Technical Impracticability Demonstration Groundwater Restoration

Little Traverse Bay CKD Release Site Emmet County, Michigan

Prepared for
CMS Land Company and CMS Capital, LLC

August 31, 2009

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Subject: Unachievable GSI Criterion Appeal to the Director under NREPA 1994 PA 451 Part 201 R 299.5716(17)

The Little Traverse Bay (LTB) Cement Kiln Dust (CKD) site (Site) is a former cement production site on this bay of Lake Michigan. The site was a brownfields redevelopment in the 1990s and includes a golf course, a residential community, and supporting commercial facilities. The brownfields redevelopment was built over and around piled CKD waste from the cement manufacturing process. The CKD piles were managed under an agreement with the State of Michigan as part of the redevelopment. It was discovered in 2004 that leachate from the CKD piles was causing high pH conditions at the water's edge. The pH in some locations exceeded 12.5 standard units (s.u.). CMS Land Company and CMS Capital, LLC (collectively referred to as CMS) have entered into a removal action AOC with the U.S. EPA to protect the public and the lake from the high pH leachate. The AOC also provides for implementation of final remedies addressing site contaminants of concern, including mercury, under the regulatory oversight of Michigan Department of Environmental Quality (MDEQ). Interim measures have been implemented at the Site, and remedial investigations and alternatives assessments (feasibility studies) have been performed as part of a process to identify and implement effective remedial actions. In the process of performing the investigations, assessments, and studies, one State of Michigan criterion has been identified as unachievable, the groundwater surface water interface (GSI) criterion of 1.3 ng/L for mercury.

CMS consulted with U.S. EPA and MDEQ as to the appropriate process to address the unachievable nature of the GSI criterion. The parties agreed that CMS should seek a U.S. EPA evaluation of a Technical Impracticability (TI) Demonstration (Demonstration) prepared in accordance with EPA Guidance Documents. This evaluation would provide the technical basis for the required elements of an appeal to the MDEQ Director that the GSI criterion for mercury is unachievable at this Site under NREPA 1994 PA 451 Part 201 Rule 716(17).

Attached is the TI Demonstration for U.S. EPA evaluation. The document discusses the completed and proposed elements of source control. At East CKD Area these include capping, diversion, and leachate collection. At Seep 1 CKD Area, source control will be provided by leachate collection and barrier wall installation. At Seep 2 CKD Area, the edge drain and beach collection systems enhanced by targeted leachate collection at Pine Court seep subarea and proposed local and regional diversion, as well as surface water control improvements will address source control. At West CKD Area, the leachate collection system as well as removal of a CKD/soil mixture from one section of the beach and replacement with a marginally permeable backfill addresses source control.

Also discussed in the document are limitations on other measures of source control such as removal and deepening of leachate collection systems.

The basis of the TI Demonstration, i.e. determination that achieving 1.3 ng/L GSI criterion is technically impracticable, is consistent with the Part 201 Rule 716(17) need to show that the criterion is unachievable. This written appeal and attached documentation coupled with the forthcoming TI evaluation provided by U.S. EPA are intended to meet the documentation requirements under Part 201 Rule 716(17) for director decision.

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Groundwater Restoration

Little Traverse Bay CKD Release Site
Emmet County, Michigan

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Executive Summary

The Little Traverse Bay Cement Kiln Dust (CKD) site (Site) is a former cement production plant on Lake Michigan. The Site was a brownfields redevelopment in the 1990s and includes a golf course, a residential community, and supporting commercial facilities. The brownfields redevelopment was built over and around piled CKD waste from the cement manufacturing process. The CKD piles were managed under an agreement with the State of Michigan as part of the redevelopment. It was discovered in 2004 that leachate from the CKD piles was causing high pH conditions at the Lake Michigan shoreline. The pH in some locations exceeded 12.5 standard units (s.u.). CMS Land Company and CMS Capital, LLC (collectively referred to as CMS) have entered into an agreement with the United States Environmental Protection Agency (U.S. EPA) to protect the public and the lake from the high pH leachate. Interim measures have been implemented at the Site, and remedial investigations and alternatives assessments (feasibility studies) have been performed as part of a process to identify and implement effective remedial actions. In the process of performing the investigations, assessments, and studies, one State of Michigan criterion has been identified as impracticable to meet, the groundwater surface water interface (GSI) criterion of 1.3 ng/L for mercury.

This Technical Impracticability (TI) Demonstration (Demonstration) applies to the GSI criterion of 1.3 ng/L for mercury. The Demonstration provides the technical framework for understanding that it is impracticable to collect or contain all mercury impacted leachate above this criterion at the Site, and furthermore that it is impracticable to treat all mercury impacted leachate to concentrations at or below 1.3 ng/L. This Demonstration includes an alternative remedial strategy (ARS) that meets the goals of protecting from exposure to the threat, controlling the source, and remediating the plume.

There are four CKD piles at the Site, distributed along approximately five miles of the Lake Michigan shoreline. These piles:

- Cover approximately 70 acres
- Are comprised of approximately two million cubic yards (CY) of CKD or approximately two billion kilograms (assumes in-place density of 80 lb/ft^3) of CKD.
- Contain mercury at a concentration of approximately 32 mg/kg on average (assumes ½ the detection limit for samples with no detection of mercury).

Water in contact with CKD produces leachate. Sources of water to the CKD piles include infiltration of precipitation and irrigation water and contact with perched groundwater or the regional water table. Leachate migrates and attenuates in the groundwater, which discharges to the surface water.

The TI zone was selected to encompass the spatial extent in which the GSI mercury criterion is likely to be exceeded. The TI zone includes the CKD piles and the leachate (and leachate-groundwater mix) migration pathways to Lake Michigan.

Several features are critical to understanding the feasible remedial actions for the Site.

- Highly fractured bedrock underlies the CKD piles and forms much of the lake shoreline.
- The CKD piles are in close proximity to the surface water (Lake Michigan).
- The terrain between the edge of the pile and the surface water is steep nearly all the way to the shoreline.
- The regional groundwater table (and gradient) under the Site is affected by local municipal well pumping.

Source removal or source control measures are technically impracticable for achieving the GSI mercury criterion. Removal would leave residual CKD at the base of excavation and in bedrock fractures, which would emit mercury above the GSI criterion for an extended period. Portions of the CKD lie below the regional groundwater table, complicating its removal. The quantity of residual CKD left after excavation could be reduced by dewatering prior to excavating, but dewatering would produce CKD leachate at volumes that cannot be managed with the available or credibly augmentable disposal capacity. In order to treat and dispose of the high rates of dewatering flow, discharge to the lake would be essential. This would require an Applicable or Relevant and Appropriate Requirement (ARAR) waiver for mercury, as the discharge water would exceed the 1.3 ng/L Great Lakes Initiative (GLI) criterion. The GLI is an initiative developed by the U.S. EPA to provide states with criteria for setting water quality standards.

Complete containment of the CKD with an on-site containment cell is technically impracticable for achieving the GSI mercury criterion for the same reasons as source removal. In situ encapsulation technologies (e.g., barrier walls, grout injections) would not assure complete isolation of the CKD as these measures could not completely seal the fractured bedrock that underlies the Site.

Complete hydraulic containment cannot be achieved with gradient control or by isolation of the waste. A zero gradient across the Site is technically impracticable due to the hydrogeologic setting; in reality there would be some inward flow from Lake Michigan and leachate would reach the pumping system. Complete hydraulic collection is not practicable, for a number of reasons, not least of which is complete collection of leachate would yield an unmanageable amount of water with mercury concentrations above the GLI criterion of 1.3 ng/L.

Even if the leachate could be collected, it is impracticable to treat it to the 1.3 ng/L GLI mercury criterion. Proven, reliable water treatment technologies may be able to remove mercury from Site leachate to concentrations in the 20 to 30 ng/L range. However, technologies currently under development to reduce the mercury concentrations further are not demonstrated at full scale, and indeed, are only in early conceptual stages, with limited success in controlled lab-scale experiments. There is no practicable technology for achieving the 1.3 ng/L criterion by treatment.

The presented ARS reduces mercury mass loading (flux) to Lake Michigan, and also protects humans and the environment from exposure to potentially harmful high pH that can be present in CKD leachate. The ARS for the Site is based on collection of the leachate at the shoreline with collection trenches. The stormwater drainage system at each CKD pile has been or will be improved, to minimize infiltration of concentrated flows of surface water. These remedial elements, common to all CKD piles, are supplemented with elements tailored to conditions at the separate CKD piles. For instance, where leachate pooled on the Site “marker shale” is sufficiently extensive, collection systems to capture the recoverable leachate are included. Where upgradient groundwater increases leachate production, diversion is included.

The ability to correctly assess both the effectiveness and the limitations of remedial measures has been demonstrated at the East CKD Area. The proposed ARS has been implemented at the East CKD Area, with the exception of the upgradient diversion system. The leachate collection trenches have reduced the leachate impact to the lake in excess of 90%. The mercury concentrations in Lake Michigan where high pH was formerly observed dropped from in excess of 1.3 ng/L before the collection trenches were installed to non-detect (less than 0.5 ng/L) once operation of the collection system began.

In contrast, CKD was removed from a portion of the East CKD area, much as would be done for a removal alternative. While that work had benefit to groundwater mercury concentrations at a downgradient monitoring well the groundwater sample concentration two years after the removal remains above the 1.3 ng/L GSI criterion.

The ARS has been demonstrated to control exposure, intercept the leachate plume, and contain the source. Full implementation of the ARS will provide a practicable remedy which is protective of human health and the environment. In contrast, attempting to remediate the Site to assure achievement of the 1.3 ng/L mercury GSI criterion would be technically impracticable.

1.0 Introduction

1.1 Purpose and Regulatory Guidance

This Demonstration report has been prepared for the Little Traverse Bay CKD Release Site, in Emmet County, Michigan.

The purpose of the Demonstration is to demonstrate that it is technically impracticable to achieve the State of Michigan GSI criterion for mercury. This State criterion can be waived under CERCLA §121(d)(4) based on several factors including Technical Impracticability, or by the State through appeal to the Director and demonstration that the GSI standard is “Unachievable” pursuant to Michigan Environmental Remediation Standards Natural Resources and Environmental Protection Act (NREPA), §20104 of 1994 PA 451 Part 201 Rule 716 (17).

The U.S. EPA has established specific guidance for evaluating the technical impracticability of attaining groundwater clean-up criteria and establishing alternative, protective remedial strategies where restoration to a criterion is not practicable. Impracticability of achieving the criterion may be demonstrated through factors such as hydrogeologic, contaminant-related, remedial technology limitations, or others. The recommended ARS provides a practicable approach to protecting human health and the environment and satisfies the statutory and regulatory requirements of CERCLA. The ARS typically addresses three items; (1) prevention of exposure to contaminated groundwater, (2) remediation of contamination sources, and (3) remediation of aqueous contaminant plumes.

The scope of this document is consistent with the Guidance for Evaluating the Technical Impracticability of Ground-Water Restoration, OSWER Directive No. 9234.2-25, dated September 1993. It includes evaluation of six TI components (below) and an ARS discussion:

- **TI Levels**: specific ARAR or Media Cleanup Standards for which TI determinations are sought
- **TI Zone**: spatial area over which the TI decision will apply
- **Conceptual Model**: model that describes Site geology, hydrology, groundwater contamination sources, transport, and fate
- **Restoration Potential**: an evaluation of the restoration potential of the Site, including data and analyses that support any assertion that attainment of ARARs or Media Cleanup

Standards is technically impracticable from an engineering perspective. At a minimum, this generally should include:

- a demonstration that contamination sources have been, or will be, removed and contained to the extent practicable;
- an analysis of the performance of any ongoing or completed remedial actions;
- predictive analyses of the timeframes to attain required cleanup criteria using available technologies; and
- a demonstration that no other remedial technologies (conventional or innovative) could reliably, logically, or feasibly attain the cleanup criteria at the Site within a reasonable timeframe.

- **Cost**: estimates of the cost of the existing or proposed remedy options, including construction, operation, and maintenance costs
- **Additional Information**: any additional information or analyses that U.S. EPA deems necessary for the TI evaluation.

1.2 Background

The Little Traverse Bay CKD Release Site is located along five miles of shoreline on Lake Michigan (see Figure 1-1). The Site is located on a former limestone mining and cement manufacturing plant that operated through 1980. For the purposes of this document, the Site is divided into two general areas: the East CKD Area and the Development Area.

The East CKD Area was developed (generally graded and covered with soil) in the 1990s and donated to Resort Township for use as a park. Detailed information on the background and history of the East CKD Area is provided in Section 1.3 of the Removal Action Investigation/Remedial Investigation Report, East CKD Area, Rev 2.0 – June 2008 Amendment 1.0 (Barr, 2009c) (hereafter referred to as the East CKD Area RI).

The Development Area was used for CKD stockpiling from approximately 1921 to 1980. The property was purchased by Bay Resort Properties Limited Partnership starting in the late 1980s through the 1990s. In 1995, the property was developed into a golf course with residential units adjacent to the CKD footprints. Detailed information on the background and history of the

Development Area is provided in Section 1.3 of the Removal Action Investigation/Remedial Investigation Report, West, Seep 2 and Seep 1 CKD Areas, Revision 1.0 (Barr, 2009a) (hereafter referred to as the Development RI).

High pH seeps were identified along the shores of Lake Michigan downgradient of the CKD piles beginning in 2004. CMS Land and CMS Capital, LLC (referred to collectively as CMS) entered into an Administrative Order on Consent (AOC) with the U.S. EPA on February 22, 2005 (VW-05-C-810) to address these observed seeps. CMS performed interim response (IR) actions under the Final Approved Removal Action Work Plan (Barr, 2005).

IR actions at the East CKD Area included installation of collection trenches downgradient of the CKD pile to intercept leachate prior to discharge into Lake Michigan, and removal and consolidation of a portion of the CKD pile ('bottleneck'). CMS has also installed infrastructure that is intended to be part of the final remedy for the Site, which includes an impermeable cover (geomembrane) system and is in process of completing an upgradient groundwater diversion system. Completed IR actions are discussed in detail in Section 1.3 of the Alternatives Evaluation, East CKD Area, Revision 0.0 (Barr, 2009d) (hereafter referred to as the East CKD Area AE). Analysis of the performance of these systems is discussed in Section 2.5.1 of this document.

IR actions at the Development Area included installation of collection trenches downgradient of the CKD piles. Additional measures include targeted removal of a portion of the sloughed CKD pile at the West CKD Area, installation of a Targeted Leachate Collection (TLC) pilot system, and construction of low-permeability cut-off walls downgradient of several of the collection trenches. The effectiveness of completed IR actions is discussed in Section 2.5.1 of this document and the integration of these measures into the proposed ARS for the Site is provided in Section 3.0.

2.0 TI Evaluation Components

2.1 Specific ARAR

The specific ARAR or Media Cleanup Standard that is the subject of this TI Demonstration is the chemical specific ARAR; State of Michigan Generic Part 201 GSI criterion for mercury. Michigan Environmental Remediation Standards NREPA, §20104 of 1994 PA 451 Part 201 establishes groundwater quality criteria that are developed for relevant exposure pathways. Criteria for groundwater based on protection of surface water resources (waters of the State) from hazardous substances in venting groundwater are included in R299.5715. The GSI criterion for mercury is 1.3 ng/L (ppt) and was established to minimize bioaccumulation of mercury through the food chain and ultimately to protect human health. The goal of this criterion is to push toward the elimination of human caused discharges of mercury to the environment.

This TI Demonstration does not apply to other contaminants of concern (COCs) that may exceed GSI criteria. These COCs are addressed by another regulatory framework, namely State rules that allow for authorization of a GSI mixing zone for the venting of groundwater from the Site into Lake Michigan.

2.2 TI Zone

The TI zone is the spatial extent over which groundwater restoration to the GSI criterion for mercury is technically impracticable. For the Site, this will include the Development Area, which is inclusive of the West, Seep 2, and Seep 1 CKD piles, and the East CKD Area. The horizontal extent of the TI zone is shown on Figure 2-1 and generally includes the CKD pile areas and extends into the Lake approximately 500 feet at the East CKD Area and 450 feet at the Development Area, which is estimated to encompass any relevant near-shore groundwater discharge at the Site. The vertical extent of the TI zone is shown on Figures 2-2 and 2-3(a through c) for the East CKD Area and Development Area. The TI zone extends to approximately 480 feet Mean Sea Level (MSL) at the East CKD Area and approximately 400 feet MSL at the Development Area. These vertical extents encompass the deepest detected extent of mercury at concentrations greater than the GSI criterion in these areas. Additional description of the TI zone determination is provided below.

2.2.1 TI Zone Horizontal Extent

The horizontal extent of the TI zone is based on a thorough understanding of the source area material extent, leachate generation mechanisms, migration pathways, and ultimate discharge to the receptor as developed through extensive research, investigation, modeling, and IR actions monitoring as discussed in Section 2.3, Site Conceptual Model (SCM).

As discussed in the SCM, mercury containing leachate is generated by water contact with CKD. Therefore, the TI zone needs to include the entire lateral extents of the CKD piles. The southern boundary of the TI zone encompasses the CKD piles in the Development and East CKD Areas and extends south to encompass the area between the CKD piles and the upgradient monitoring wells. The eastern and western boundaries of the TI zone are established coincident with nearby creeks, with the exception of the west side of East CKD Area which is bounded in Village Harbor. The locations of the creeks and their identifiers are shown on Figure 2-1. The creeks are appropriate lateral limits for the TI zone because they are discharge zones for water table groundwater, and as such represent the east-west limits beyond which the relevant groundwater would not be expected to migrate. The leachate migration pathway is predominantly toward the lake, so leachate is not expected to migrate towards the creeks. This expectation is supported by the observation that the creek monitoring data have shown no impacts from CKD.

The northern boundaries of the TI zone and the western boundary of the East CKD Area are established by near-shore regional groundwater discharge to Lake Michigan and Village Harbor. Multiple lines of evidence were used to define the discharge zones of potentially impacted groundwater in order to define these boundaries of the TI zone. The evidence includes aerial thermometry, lakeshore monitoring, and groundwater flow pathways using the groundwater flow models developed for the Site. The furthest northern extent of the three was the aerial thermometry, which showed temperature increases of approximately 1 degree Celsius above ambient lake temperature extending from the shoreline approximately 500 feet into the lake. This may be a conservative estimate, as various wind, current, solar heating, and other factors may dominate the near-shore surficial temperature, rather than groundwater discharge temperature. The lakeshore monitoring, which includes multiple rounds of pH monitoring, showed observable leachate impacts in surface water less than 100 feet off the northern shoreline. Results from the Michigan Department of Environmental Quality (MDEQ) ice study at East CKD Area (see Appendix Q of the East CKD Area RI) confirmed that leachate impacts were near shore; investigation lines A and C, which were approximately 350 feet and 500 feet off the shoreline, did not contain observable leachate impacts. Flow pathways were estimated using the “particle tracking” feature of the groundwater model. The tracks are estimated by placing simulated particles at the bottom elevation of the TI zone in the groundwater model and then allowing the particles to move with the groundwater flow until they reached the lake. The modeled flow pathways terminated generally between the observable leachate impacts (100 feet) and the temperature increase associated with the aerial thermometry survey (500 feet). Thus, the use of the aerial thermometry survey to provide a northern extent is inclusive of the Site data and provides an appropriate representation of probable discharge for the CKD leachate.

Each line of evidence used in establishing the northern boundaries of the TI zone is consistent with the understanding that regional groundwater flow converges in the vicinity of a surface water body, as shown on Figure 2-4 (Rosenberry, 2008), limiting the discharge of CKD leachate to the near-shore zone.

The western limit of the TI zone at the East CKD Area in Village Harbor was established by reviewing the lakeshore monitoring, which showed some high pH impacts near the shoreline and particle tracking that terminated at or just beyond the lakeshore impacts. The aerial thermometry did not provide additional benefit for determination of the zone extent in this area.

Additional detail on the aerial thermometry survey is included in Appendix 3-1 of the Development RI. Lakeshore pH monitoring is included in Appendices 2-1, 2-7, and 2-8 of the Development RI and in Appendices L, Y, and Z of the East CKD Area RI. MDEQ ice study data are included as Section 1.3.4 and Appendix Q of the East CKD Area RI, and the groundwater model and use of particle tracking is discussed in Appendix T of the East CKD Area RI and the Groundwater Modeling Report West, Seep 2, and Seep 1 CKD Areas Revision 0.0 – July 31, 2009 (Barr, 2009f).

2.2.2 TI Zone Vertical Extent

The vertical extent of the TI zone was established to encompass the lowest elevations at which mercury above 1.3 ng/L has been detected in groundwater samples collected from monitoring wells. In general, the mercury concentrations diminish with depth as lower screen intervals intersect regional groundwater that is either unimpacted or minimally impacted by the leachate plume. The bottom of the TI zone at the East CKD Area and Development areas are 480 feet MSL and 400 feet MSL, respectively. Additional information on monitoring well water quality is provided in Section 5.0 and Tables 5-6a through 5-6c of the Development RI and in Section 4.0 and Table 2-5 of the East CKD Area RI.

2.3 Site Conceptual Model

The SCM provides the foundation for evaluating the restoration potential of the East CKD and Development Areas and technical impracticability of achieving the GSI criterion for mercury. The SCM fully integrates and provides a synthesis of all data acquired from research, investigation and characterization, and performance of IR operations at the Site. The primary elements of the SCM are the geology, groundwater flow mechanisms/aquifer characteristics, surface water evaluations, leachate generation mechanisms, and leachate migration pathways to Lake Michigan. Specific features or key factors associated with each of these elements that relate to the practicability of achieving the GSI criterion or provide the basis for the selection of the ARS are discussed in greater detail in this section and are based on the information provided in the RIs and Alternatives Evaluations (AEs) that have been prepared for the Site: East CKD Area AE and Alternative Evaluation, West, Seep 2, Seep 1 CKD Areas, Revision 0.0 (Barr 2009b) (hereafter referred to as the Development AE).

The SCM is presented for the entire Site. Where there are distinguishing characteristics for an individual CKD pile area, they are noted. Each CKD area has been extensively investigated and analyzed to produce this SCM which characterizes the generation, transport, and fate of mercury to a level of detail sufficient for remedial alternative selection and technical impracticability assessment. Figures for the East CKD and Development Areas, which identify features that are discussed in the following sections, are shown on Figures 2-5 and 2-6(a-b). A generalized Site geologic cross-section is shown on Figure 2-7a.

The SCM supports the finding that elimination of mercury generation within the CKD pile areas or of mercury flux to Lake Michigan is impracticable. In general, the SCM shows that several dominant mercury generation mechanisms and routes of migration are present. Additionally, several non-dominant mercury generation mechanisms exist at each CKD pile area. It is impracticable to address each generation mechanism at all CKD pile areas because residual mercury generation will persist for all remedial process options and technology types considered in the AEs. It is also impracticable to mitigate all routes of mercury migration to Lake Michigan because of the nature of fractured bedrock. Operation and monitoring of the extensive IR beach collection drain systems supports this conclusion. Although the IR drains are effective at mitigating mercury flux to the lake, some mercury mass migration to Lake Michigan will persist. The alternatives proposed in the AE Reports are implementable and provide a practicable mitigation of mercury flux to Lake Michigan.

Individual SCMs and remedial alternatives for the West, Seep 2, and Seep 1 CKD Areas are fully described in the Development Area AE. The East CKD Area SCM and remedial alternatives are fully described in the East CKD Area AE. The SCM in this Demonstration sufficiently describes pertinent concepts related to mercury at each CKD area; however CKD pile-specific references to data (e.g., well boring logs, tables, figures) for all findings are only included in the AE Reports.

2.3.1 Development of Site Conceptual Model

The SCM has been developed and refined with observations and data from the investigation activities conducted at the East CKD and Development Areas. Additionally, observations, data collection, and analysis from the IR activities (including augmentation) and the subsequent operational and effectiveness monitoring of the IR activities have been used to refine the SCM. Investigation activities and IR activities completed at the Site include the following:

- Preliminary Investigations – Includes activities and investigations conducted prior to approval of the Removal Action Work Plan (RAWP or Work Plan). Including review of available information regarding the Site setting, surface geophysical investigations, preliminary lakeshore evaluation, limited beach pool sampling, and geologic mapping.

- Expedited Removal Actions – Includes Work Plan activities completed prior to final approval of the RAWP. Including targeted shoreline survey and overflights.

- Response Action Investigations – Includes Removal Action (RA) Investigation Activities completed as a part of the Work Plan. Including topographic surveys, aerial thermometry, extent and characterization of CKD piles, hydrogeological investigations, determination of geologic and hydrogeologic properties, surface water investigations, geophysical investigation, baseline ecological investigation, and other investigations included in the RI Reports.

- Supplemental Investigations – Include investigation activities conducted to supplement the RA Investigation Activities. Including installation of additional boreholes and monitoring wells, evaluation of Edge Drain, assessment of CKD in Lake Michigan at the East CKD Area, aquifer testing and geophysics investigation along the Seep 1 CKD Area beach, and drainage system survey.

- Additional Investigations – Includes the Village Harbor Investigation, Bay Harbor Lake Assessment, and the MDEQ Ice Study.

- IR Actions – Includes the construction of the IR components and operational monitoring and effectiveness monitoring of the IR components which were conducted as a part of the Work Plan.

- IR Augmentation – Includes the activities conducted to improve the IR collection drain performance following initial construction.

- Flux Investigation – Includes the investigations and evaluations conducted to assess the flux of mercury. Including an evaluation of mercury flux using data from RAWP activities, installation of additional shoreline wells, slug testing of all shoreline wells, conducting mini pumping tests of shoreline wells, and mercury sampling and analysis.

- Final Remedy Design – Includes the diversion well design work. Including installation of diversion wells and observation wells, conducting pumping tests, and groundwater modeling.

Key elements of the SCM were defined during the Preliminary Investigations and Implementation of the Work Plan Activities (IR Actions, Expedited Removal Actions, and RA Investigation Activities). Subsequent investigations and IR activities have generally refined and/or confirmed, but not materially amended the SCM. Development and evolution of the SCM with respect to all the investigation activities listed above is summarized in Table 2-1. Additional detail of investigations is presented in the RI Reports.

2.3.2 Site History

For much of the 20th century, the majority of the Site was designated for industrial use and included mining operations and cement production. The dominant features associated with the historical property use include a former cement plant, shale quarry, central limestone quarry, eastern limestone quarry, and four separate CKD piles as shown on Figure 1-1. CKD was stockpiled on the Site from approximately 1921 to 1980 (NTH, 1994).

The Site is now owned by Bay Harbor Golf Club, Inc., private property owners, CMS, Bay Harbor Company, and Resort Township. Golf course fairways and rough areas and a park have been constructed over the CKD piles.

2.3.3 Geologic and Hydrogeologic Setting

2.3.3.1 Geology

Stratigraphy at the Site generally consists of soil/unconsolidated sediments and/or CKD overlying bedrock. The bedrock at the Site is part of the Traverse Group and consists primarily of limestone with some interbedded shaley limestone or shale. There is a locally significant unnamed shale layer referred to as the “marker shale”, which underlies much of the Seep 2 CKD Area and portions of the Seep 1 and West CKD Areas. The upper elevation of the marker shale ranges from approximately 50 to 100 feet above Lake Michigan; the shale extends to within 200 feet of the lake. The SCM with the presence of a perching media, such as shale, is shown on cross-section on Figure 2-7b.

The upper portion of the limestone bedrock tends to be weathered, though effects of weathering diminish with depth. However, the fracture density in the bedrock does not decrease noticeably with depth. The bedrock is densely fractured by both low angle bedding plane fractures and high angle subvertical fractures. In outcrop, spacing of the high angle fractures range from one to two feet. Borehole logging by acoustic televiewer indicates that the average fracture density is 1.2 fractures/foot. Fracture widths range from approximately 1mm to 100 mm. No large-scale dissolution features have been identified at the East CKD or Development Areas (i.e. karst features are not present).

2.3.3.2 Groundwater

Since the predominant bedrock type under the East CKD and Development Areas is limestone, it was assumed prior to investigation activities that groundwater at the Site flowed primarily through a limited number preferential flow paths (i.e. conduits). Investigation activities were designed and structured to either prove or refute this hypothesis. No conduits were identified during the extensive investigation activities at the East CKD and Development Areas. Therefore, it is concluded that the groundwater flow system at the Site (1) is through a dense interconnected fracture system within the bedrock and (2) can be approximated as an equivalent porous medium.

Groundwater flow at the Site occurs in two distinct regimes: regional groundwater flow and perched groundwater flow. Regional flow occurs throughout the Site and is influenced primarily by upgradient recharge, the elevation of Lake Michigan and pumping from municipal wells. Perched flow occurs where infiltrating groundwater pools on the marker shale or other low permeability units, which act as leaky aquitards. Perched groundwater flow is influenced primarily by recharge due to rainfall and irrigation; it is not affected by lake elevations because the low permeability units are above the elevation of the lake.

The depth to regional groundwater across the Site is variable, and the horizontal hydraulic gradient is typically oriented towards Lake Michigan. The horizontal hydraulic gradient steepens toward Lake Michigan and ranges from approximately 0.04 to 0.07 feet/foot (average value of 0.06 feet/foot). Lake Michigan is the regional discharge zone for groundwater in the vicinity of the East CKD and Development Areas. Nearly all regional groundwater discharge that could potentially be impacted by leachate occurs in the near-shore zone, within approximately 400 feet of the shoreline.

As noted above, municipal water supply wells have created localized sinks for groundwater and seasonally alter the regional groundwater flow patterns beneath much of the Development Area. The City of Petoskey operates three high-capacity water supply wells (City Well 3, City Well 4, and City Well 5) near the southern boundary of the Development Area. The groundwater elevations at the Development Area during high and low pumping periods are shown on Figures 2-6a and 2-6b. A SCM cross-section showing the effect of high regional pumping is included as Figure 2-7c.

Perched groundwater occurs at the West, Seep 1, and Seep 2 CKD Areas; only the Seep 2 Area exhibits significant quantities of perched groundwater. The perched groundwater at the Seep 2 CKD Area is seasonally 30 feet or more above the regional groundwater elevation because the regional water table below the shale is drawn down by the City of Petoskey municipal wells during time of high water use. During these high pumping periods, unsaturated conditions develop below the marker shale beneath the Seep 2 CKD Area. During periods of lower municipal well pumping, the regional piezometric surface is generally above the bottom of the marker shale.

Water quality has been monitored in upgradient monitoring well nests installed in the East CKD Area and in the Development Area as presented in the East CKD RI and Development RI. Mercury impacts have been identified, with concentrations ranging from less than the reporting limit of 0.5 ng/L to 11.5 ng/L. The mercury impacts could be derived from many sources, both natural and manmade, but are not likely to be related to the presence of CKD leachate since the samples have ionic balances representative of groundwater, the pH is near neutral, and the specific conductivity is relatively low compared with leachate. Specifically, the pH of these samples ranged from 5.4 to 7.8 and the specific conductance ranged from 429 to 1,653 μmhos. The Site data indicate that groundwater from upgradient of the Site contains mercury at concentrations above the GSI limit of 1.3 ng/L.

2.3.3.3 Surface Water

A surface water divide is located approximately one-half mile south of the Development Area. Surface water south of this divide flows generally south-southwest toward Walloon Lake; surface water north of the divide flows generally north toward Lake Michigan. There are three unnamed creeks in the vicinity of the Site, which are surface expressions of the water table.

2.3.4 Contaminant Source (CKD Piles)

The source of contamination at the Site is the CKD piles. The location of the CKD piles is shown on Figure 1-1. CKD is a by-product of portland cement production and is a particulate mixture of partially calcined and un-reacted raw limestone feed, clinker dust, and fuel ash, enriched with alkali sulfates, halides, and other volatile inorganic materials. The results of the chemical analysis of CKD samples collected during the RI show that the dominant chemicals include calcium, magnesium, aluminum, iron, sulfate, chloride, potassium, and sodium. Many of these chemicals are present as oxides that will react with water to form hydroxides. The CKD material also contains small quantities or trace amounts of metals and inorganic compounds including arsenic, barium, chromium, copper, lead, mercury, nickel, selenium, silver, thallium, vanadium, and zinc (See Table 2-2 in the East CKD RI and Tables 5-4a-c in the Development RI).

The following sections describe the extent of CKD piles and their relationship to hydrogeologic features.

2.3.4.1 West CKD Area

The West CKD pile covers an area of about 5.4 acres and contains approximately 100,000 CY of CKD. The pile is generally prism-shaped with a near-horizontal upper surface, and a lower surface that deepens northward, toward an escarpment at the beach. The majority of the West CKD pile is located above the regional groundwater table. The exception is the northern toe of the central portion of the CKD pile which is seasonally saturated by the regional groundwater table.

CKD was present on the beach in this area but was removed in 2008/2009 as part of augmentation activities. This CKD was mixed with soil and was relatively shallow, generally within the top five feet from the surface. On the eastern portion of the beach area, CKD/soil was in direct contact with bedrock. CKD was identified in a sandy gravel matrix from boring activities in the area. For example, the presence of CKD was identified to about 570 feet MSL at B3032 (see Development RI Figure 3-1a) with a field pH of 10 s.u. However, during excavation, the bedrock surface was identified at about 576 feet (see record drawing C-02R in Appendix 2-3 of the Development RI). The bedrock was fractured enough to allow a geoprobe boring to be advanced almost 6 feet into the rock and provides field evidence of the presence of CKD in fractured bedrock beneath the CKD source material.

2.3.4.2 Seep 2 CKD Area

The Seep 2 CKD pile is situated parallel to Lake Michigan. It covers an area of about 34.8 acres and contains approximately 1.1 million CY of CKD. The entire Seep 2 CKD Area is underlain by limestone; a “marker” shale layer is present approximately 30 feet beneath the limestone surface. The shale generally appears to dip to the south under the western side of the pile, and to the north under the eastern side of the pile. Groundwater is locally perched on the shale, which acts as a leaky aquitard. The majority of the CKD at the Seep 2 CKD Area lies above the regional groundwater table. Variable saturated CKD can be found along the northern edge of the CKD pile in the vicinity of the "Edge Drain" which is the original collection drain.

2.3.4.3 Seep 1 CKD Area

The Seep 1 CKD Area consists of one CKD pile situated parallel to Lake Michigan. The pile covers an area of about 15.5 acres and contains approximately 550,000 CY of CKD. The western and central portion of the Seep 1 CKD pile lies on limestone bedrock at its southern half, and soil at its northern half. The eastern side of the pile lies on soil above limestone bedrock. Two bedrock depressions at the center of the pile contain CKD saturated by the regional groundwater table. The "marker" shale is largely absent in the Seep 1 CKD Area. Hence, the shale is not a significant factor in leachate flow in this area. Although the shale at the west end of the pile may seasonally perch groundwater, it acts as a leaky aquitard.

2.3.4.4 East CKD Area

The East CKD Area consists of one CKD pile situated parallel to Lake Michigan, with its long axis having an east-west orientation. The surface area of the current extent of CKD is approximately 10.2 acres. Soil fill and/or CKD fill were placed in topographic lows, directly over the weathered limestone bedrock. The bedrock surface undulates and generally forms an east-west trough with a closed eastern end; it is likely the result of historical quarrying activities. Bedrock is currently present at depths ranging from two feet to 55 feet below ground surface. At the deepest portions of the East CKD pile, the regional groundwater table contacts the CKD.

2.3.5 Leachate Generation Mechanisms

The following section describes the mechanisms for leachate generation at the Site followed by a discussion of the specific mechanisms that are pertinent to each CKD Area.

Leachate is generated when water, in excess of the hydration demand, comes in contact with CKD. Upon contact of CKD with water, chemical reactions take place resulting in physical and chemical changes in the CKD and water as follows:

- free lime hydration contributes hydroxide alkalinity to the leachate and remove calcium and magnesium from the leachate
- silicate hydration contributes hydroxide alkalinity, as well as small amounts of calcium and silicon to leachate

- aluminate hydration in CKD contributes hydroxide alkalinity, as well as small amounts of calcium and aluminum to leachate
- aluminoferrite hydration contributes hydroxide alkalinity, as well as small amounts of calcium, aluminum, and iron to the leachate
- alkali oxide reactions contribute hydroxide alkalinity, as well as small amounts of potassium
- sulfate salts of potassium and sodium dissolve readily in water, contributing high concentrations of dissolved solids to the leachate
- saponification of organic matter results in the production of fatty acid surfactants that reduce the surface tension of the leachate, making it a better wetting agent and binding site for mercury

Some of the hydration reactions, namely aluminate and aluminoferrite hydration, may be significantly retarded by sulfate in the CKD.

The net effect of the reactions described above is to impart some specific properties to leachate:

- Relative to natural waters, leachate is enriched in sodium and potassium, but depleted in calcium and magnesium.
- Leachate has a high pH.
- Leachate has high concentrations of sulfate and total dissolved solids.
- Leachate will have varying concentrations of aluminum and iron, depending on the degree to which sulfate has leached out of the CKD. Aluminum will elute from a CKD pile earlier in the weathering process than iron, due to differences in hydration rates.
- Fatty acid surfactants impart total organic carbon to the leachate, as well as a lower surface tension relative to water.
- Leachate has elevated concentrations of mercury.

Leachate at the Site is generated by one of the following mechanisms:

1) Perched or regional groundwater intersects and saturates CKD.

2) Vadose zone water (from infiltration) flows laterally over the top of a CKD surface (i.e. interflow), thereby contacting the CKD. The median vertical permeability of shallow non-

CKD soils at the Site is approximately 140 times greater than the median permeability of Site CKD. Therefore, surface water infiltration is expected to preferentially flow along the surface of the CKD, rather than infiltrating downward through the CKD. Interflow along the CKD surface is evidenced by the findings from the geotechnical investigation of the Seep 2 CKD Area slope failure. It was determined that the slope failure was due to increased moisture and pore pressure at the interface between the cover material and the CKD surface, thereby illustrating that vadose zone water collects and flows along the CKD surface.

3) Vadose zone water (from upgradient) flows laterally along the top of a bedrock surface, thereby contacting CKD that is in close proximity to the bedrock surface.

4) Infiltration (i.e. vadose zone water migrating vertically) percolates downward through a CKD pile. This occurs in places where the surface topography is generally steep and water collects in depressions in the ground surface and CKD surface.

Leachate generation mechanisms are identified on the conceptual cross-sections, Figures 2-7a through 2-7c.

2.3.5.1 West CKD Area

The dominant mechanism of leachate generation at the West CKD Area is CKD saturation by perched and regional groundwater. However, interflow and infiltration also generate leachate, as described below.

- A clay layer beneath the western and central portions of the CKD pile perches groundwater above it, thereby allowing the perched groundwater to contact CKD and generate leachate.

- Interflow (i.e. horizontal unsaturated flow) occurs along the top of the West CKD pile, producing leachate that emerges near the bottom of the escarpment.

- Infiltration (i.e. vertical unsaturated flow) generates leachate by migrating downward through the CKD in the eastern portion of the CKD pile where the clay layer is not present.

To substantially eliminate these dominant generation mechanisms, the West CKD pile would have to be removed or perched groundwater flow would have to be eliminated and regional groundwater elevations in the central portion of the pile would need to be lowered year-round below the minimum CKD elevation.

In addition to addressing the dominant mercury generation mechanisms, to ensure that mercury concentrations greater than 1.3 ng/L do not persist in groundwater discharging to Lake Michigan at the West CKD Area, mechanisms such as interflow and CKD that has migrated into underlying bedrock would require mitigation. Groundwater sample analysis at the East CKD ‘bottleneck’ Area demonstrates that mercury concentrations in the groundwater greater than 1.3 ng/L persists following removal activities. Mercury persists because even after removal of the CKD pile, residual CKD will remain at the base of excavation and in the bedrock fractures as discussed in Section 2.4.1.

2.3.5.2 Seep 2 CKD Area

The dominant mechanism for leachate production at the Seep 2 CKD Area is perched groundwater saturating CKD in the northern portion of the pile. Interflow may also contribute to leachate generation at the Seep 2 CKD Area but is not the dominant mechanism.

The leachate observed at the Pine Court seep subarea is predominantly generated by saturated CKD in the vicinity of the borehole S2RW-2. During investigation activities, saturated CKD was encountered at this location. Monitoring data from other wells in the vicinity of borehole S2RW-2 indicate that high pH perched leachate is present. Additionally, monitoring data from these wells show that high pH leachate persists despite ongoing pumping from TLC extraction wells installed to collect high pH water from this area. These findings support the conclusion that saturated CKD is present in the vicinity of boring/well S2RW-2 and is a dominant mechanism for leachate production in this area.

The leachate observed at the Seep 2 and Guard Rail seep subareas is predominantly generated by CKD saturated by perched groundwater located along the northern edge of the marker shale at the central and western parts of the Seep 2 CKD pile. Comparison of perched groundwater elevation data and the bottom of CKD contours reveals that saturated CKD is present at locations along the northern slope of the CKD pile. This conclusion is also supported by the fact that the Edge Drain collects high pH leachate year-round.

Less important leachate generation mechanisms in the Seep 2 CKD Area include interflow across the top of CKD and interflow on top of the limestone bedrock where CKD is in contact with or near the bedrock surface.

One exception to the generalized condition that infiltration will migrate as interflow across the top of the CKD is in the area near well S2RW-2 extending down slope to borehole B2006 (see Development RI Figure 3-1b). This area is in the vicinity of borehole S2RW-2 (see Figure 3-3) where saturated CKD was observed. In this area, the steep surface topography suggests that interflow would tend to pool near the toe of the slope which may result in increased infiltration of water into the CKD pile.

Other locations where infiltration is more likely to occur at the Seep 2 CKD Area include flat or depressed CKD surface areas where storm or irrigation water would tend to pond. Areas with these characteristics include a depressed surface area east of boring B2058 (located at the western extent of the main Seep 2 CKD pile) and south of borehole S2RW-2. These two low areas are adjacent to areas on the western half of the Seep 2 CKD Area where high pH leachate has been observed on the marker shale. In further support of these findings is elevation monitoring data at well S2OW-1, west of well S2RW-2, which shows perched groundwater being more responsive to precipitation events than other wells in the area. These observations support the conclusion that infiltration through the CKD at specific areas in the Seep 2 CKD Area is a relevant mechanism for generating leachate.

Bedrock surface interflow is generally a result of upgradient surface water infiltration flowing along the top of the bedrock surface. In areas where CKD is near or directly on top of bedrock, leachate is expected to be generated when interflow along the bedrock surface contacts the overlying CKD. CKD was observed to be within one foot of the bedrock near well S2RW-2 and east of borehole B2058 making it possible to generate leachate from bedrock surface interflow. Evidence of bedrock surface interflow was observed in three borehole locations in the western half of the Seep 2 CKD Area (B2042, B2049, and S2OW-1) where wet soils were located above unsaturated limestone.

Leachate generation from interflow and infiltration is expected to vary based on precipitation (rainfall/snowmelt) and the locations of generation are expected to be difficult to isolate. When borehole B2006 was drilled in December 2005, moist soil was observed immediately above the bedrock, and when borehole S2OW-1 was drilled in April 2008 (after a 1.2 inch rain event on 4/25-26/08), wet soil was observed immediately above the bedrock. These two borings were drilled at the same location. These observations support the conclusion that the bedrock surface interflow is dependent on rainfall/snowmelt events. These observations also provide evidence that bedrock surface interflow is intermittent and is not easily located. The effect of precipitation on leachate generation is also correlated to fluctuation in elevations and flows observed in the IR drains.

The dominant leachate, and thus mercury, generation mechanisms at the Seep 2 CKD Area are perched groundwater saturating CKD in the vicinity of well S2RW-2 and at the northern extent of the central and eastern portions of the pile. To substantially eliminate these dominant generation mechanisms, the Seep 2 CKD pile would have to be removed or perched groundwater flow would need to be eliminated.

In addition to addressing the dominant mercury generation mechanisms, to ensure that mercury concentrations greater than 1.3 ng/L do not persist in groundwater discharging to Lake Michigan at the Seep 2 CKD Area, mechanisms such as bedrock interflow (i.e., flow along the top of the bedrock) contact with CKD, interflow across the top of the CKD, and CKD that has migrated into fractures in underlying bedrock would require mitigation. Groundwater sample analysis at the East CKD 'bottleneck' Area demonstrates that mercury concentration in the groundwater greater than 1.3 ng/L persist following removal activities. Mercury persists because even after removal of the CKD pile, residual CKD will remain at the base of excavation and in the bedrock fractures as discussed in Section 2.4.1.

2.3.5.3 Seep 1 CKD Area

The dominant mechanisms for leachate generation at the Seep 1 CKD Area are: CKD saturated by the regional groundwater table and interflow, as described below.

- The regional groundwater table intersects CKD in an isolated area in the central portion of the CKD pile, where approximately 7 to 20 feet of CKD is saturated seasonally. The isolated area of CKD saturated by regional groundwater represents less than approximately 1% of the Seep 1 CKD pile.

- Leachate at the Seep 1 CKD Area is generated by interflow along the top of the CKD pile. The significance of leachate generation by interflow at the Seep 1 CKD Area is evidenced by the "road seep" discussed in Section 2.1.5 of the Development RI Report and the shallow nature of the initial Seep 1 CKD Area shoreline impacts.

- Leachate at the Seep 1 CKD Area is generated by interflow on top of the limestone bedrock where CKD is in contact with or near the bedrock surface. CKD was observed to be within two feet of the bedrock surface at several borehole locations making it possible to generate leachate from bedrock surface interflow.

To substantially eliminate these dominant leachate generation mechanisms, the Seep 1 CKD pile would have to be removed or infiltration over the CKD pile would have to be eliminated (interflow across top of CKD), infiltration upgradient of the CKD pile would have to be eliminated (interflow contacting CKD near the bedrock surface), and regional groundwater elevations in the central portion of the pile would have to be lowered year-round below the minimum CKD elevation (saturated CKD).

In addition to addressing the dominant mercury generation mechanisms, to ensure that mercury concentrations greater than 1.3 ng/L do not persist in groundwater discharging to Lake Michigan at the Seep 1 CKD Area, mechanisms such as CKD that has migrated into underlying bedrock fractures and perched groundwater contact with CKD at the western portion of the CKD pile would require mitigation. Groundwater sample analysis at the East CKD ‘bottleneck’ Area demonstrates that mercury concentrations in the groundwater greater than 1.3 ng/L persist following removal activities. Mercury persists because even after removal of the CKD pile, residual CKD will remain at the base of excavation and in the bedrock fractures as discussed in Section 2.4.1.

2.3.5.4 East CKD Area

Prior to implementation of the IR actions, the primary sources of leachate generation at the East CKD Area were CKD saturated by regional groundwater and, to lesser extents, infiltration and CKD saturation by perched groundwater. However, the sources of leachate generation at the East CKD Area have been altered as a result of the IR actions.

At the East CKD Area, the main mechanism of leachate generation pre– and post– IR actions is regional groundwater contacting CKD. Excavation of CKD from the ‘bottleneck’ has eliminated most of leachate generation from saturated CKD in this portion of the East CKD Area. While some CKD remains entrained in the fractured bedrock after the excavation of the ‘bottleneck’ area, leachate generation from these residuals have not caused pH exceedances in the lake. As a component of the final remedy, a groundwater diversion system has been designed to reduce leachate generation from groundwater contacting CKD and to reduce the volume of groundwater flowing through the remaining saturated CKD.

Areas of higher infiltration existed at the East CKD Area prior to the IR actions (Figure 2-5). For example, an area of lower topography was located upgradient of the southwest corner of the Site in the area of boreholes B4016 and B4051 (see Figure 2-1a of the East CKD RI). High pH levels observed during the targeted shoreline survey along the shoreline in the southwest corner (Figure 2-8) were likely a result of leachate generated from infiltration in this low area. Subsequent to the IR actions, effectiveness monitoring conducted along the shoreline near the southwest corner of the CKD pile resulted in no pH readings greater than 9.0. Another area of suspected high infiltration was located upgradient of the western portion of the CLCS along the old Quarry Drive alignment. Poorly drained ditches allowed surface water to infiltrate into the CKD pile. Elevated pH readings were recorded during the targeted shoreline survey downgradient of the old ditches. Subsequent to IR actions, no pH readings above 9.0 have been observed in Lake Michigan and the pH observed in piezometer EP2-PZ1 (located in the western portion of the CLCS trench) was between 7.0 and 9.0 indicating a substantial reduction in leachate generation in this area. The original parking lot was designed to drain water to an infiltration area where surface water likely infiltrated the CKD pile generating leachate. These areas of higher infiltration were eliminated as a result of the IR actions. The consolidation of the CKD, installation of the geomembrane cover system, and stormwater improvements have eliminated most leachate generation from infiltration in the western and central portions of the East CKD Area. Additionally, excavation of the CKD from the 'bottleneck' has eliminated most leachate generation from infiltration in that portion of the East CKD Area.

Interflow from upgradient perched groundwater contacting CKD is another source of leachate generation at the East CKD Area. Perched groundwater was identified in the vicinity of B4078 and during the installation of stormsewer and the LCS forcemain upgradient of the CKD pile. Draintile was installed along the west diversion well header pipe trench and along the southern forcemain and stormsewer pipe trenches as shown in the record drawings (East CKD Area RI, Appendix X). The draintile was installed to collect this shallow upgradient groundwater reducing the amount of perched groundwater contacting CKD. The amount of leachate generated from perched groundwater contacting CKD is not expected to be significant in relation to the amount the leachate generated from saturated CKD.

2.3.6 Leachate Migration

Leachate migration at the East CKD and Development Areas is generally through advection by groundwater flow. On a localized scale leachate may migrate downward as a result of density differences; however, this phenomenon is limited due to leachate mixing with groundwater (dilution) and the upward vertical flow of groundwater as it nears Lake Michigan. As discussed in Section 7.3 of the Development RI, Site samples fall into a wide-ranging continuum with respect to the ratio of divalent:monovalent cations (Ca+Mg : Na+K). As expected, pH is attenuated as the ratio of divalent:monovalent cations increases, due to dilution, precipitation of carbonate alkalinity, and neutralization with groundwater acidity. Mercury is also attenuated as the ratio of divalent:monovalent cations increases, due to dilution as well as precipitation of the mercury-bearing fatty acid surfactants.

The leachate migration mechanisms are shown on the SCM cross-sections, Figures 2-7a through 2-7c.

2.3.6.1 West CKD Area

The clay layer beneath the central part of the West CKD Area restricts downward movement of leachate. However, as perched leachate migrates northward toward the Lake Michigan, the clay layer ends and leachate migrates downward to the bedrock valley and into the regional groundwater. Leachate is also observed to migrate downward to the regional groundwater table on the east side of the pile where the clayey soil is absent. Leachate in the regional groundwater (both from perched and regional groundwater contact with CKD) is subjected to seasonal gradient reversal during peak pumping of City Well 5, causing the leachate to migrate further downward in the regional aquifer.

Leachate generated from interflow across the top of the CKD pile migrates north toward Lake Michigan and then downward to the shallow regional groundwater.

Migration of shallow leachate to Lake Michigan is effectively mitigated by operation of the West CKD IR beach collection drains that intercept leachate flow adjacent to the shoreline. Capture of leachate flow in these drains is enhanced by the modified fill zone installed downgradient of the drain during 2008/2009 IR augmentation activities. The modified fill is a low permeability fill material that was installed to address exceedances measured along the shoreline adjacent to the IR drains by cutting off the flow path in the unconsolidated material along the beach.

Leachate does not impact the municipal wells. Although regional groundwater gradients are seasonally reversed during times of high groundwater usage no pH exceedances have been observed in upgradient well nests. Neither analyte exceedances nor occurrences of elevated pH have been measured in the west unnamed creek, demonstrating that the creek is not impacted by CKD.

2.3.6.2 Seep 2 CKD Area

Leachate generated from saturated CKD in the vicinity of well S2RW-2 migrates over and through the marker shale to the regional groundwater. The influence of high pumping at City Well 5 draws high pH leachate from this area downward and to the southwest. During times of low pumping at City Well 5, the high pH leachate resumes the expected northward flow toward Lake Michigan. Over time, the seasonal cycling of City Well 5 results in migration of leachate from the area near borehole S2RW-2 area to the Pine Court seep subarea. In monitoring wells immediately southwest of well S2RW-2, wells screened below the marker shale show higher pH than wells screened above the marker shale. The fact that pH in the regional groundwater below the marker shale has higher pH than the perched groundwater above the marker shale is consistent with the migration pathway of leachate from the S2RW-2 location to the Pine Court seep subarea.

Leachate generated from saturated CKD in the central and eastern portions of the Seep 2 CKD Area that is not collected by the Edge Drain migrates over and through the maker shale to the regional groundwater table. Since pumping at City Well 5 is less influential in these areas relative to the Pine Court seep subarea, leachate mixes less with upgradient groundwater and does not migrate as far down into the regional groundwater. This leachate is intercepted by the Seep 2 collection drain.

Leachate and impacted regional groundwater at the Seep 2 CKD Area discharge within close proximity of the shoreline as evidenced by the upward hydraulic gradients observed in the Seep 2 CKD Area beach wells. The lack of pH exceedances in deep monitoring wells located adjacent to the Lake Michigan shoreline, in particular at the Seep 2 seep subarea, provides additional evidence of an upward vertical gradient and migration of leachate within close proximity to the shoreline.

Even though the regional groundwater gradient seasonally reverses during times of high municipal water usage, leachate does not impact the municipal wells. This statement is supported by water quality monitoring data from upgradient well nests located between the Seep 2 CKD pile and the nearby municipal wells.

Migration of shallow leachate and impacted deeper regional groundwater to Lake Michigan is effectively mitigated by operation of the Seep 2 and Guard Rail IR beach collection drains that intercept leachate flow adjacent to the shoreline. Migration of shallow leachate, and to a lesser extent, impacted deeper regional groundwater to Lake Michigan is effectively mitigated by operation of the Pine Court IR beach collection drains. The exception at the Pine Court seep subarea is a deeper zone of impacted groundwater that appears to seasonally discharge outside of the Pine Court IR beach collection drain capture zone.

2.3.6.3 Seep 1 CKD Area

Shallow leachate migrates through the CKD pile and underlying soil toward Lake Michigan and downward to the regional groundwater as evidenced by pH exceedances in shallow and deep monitoring wells, respectively. Monitoring well data show that regional groundwater within the Seep 1 CKD Area has an upward gradient and discharges within close proximity of the shoreline.

Additionally, groundwater pH exceedances are not evident in deep monitoring wells located adjacent to the Lake Michigan shoreline. These trends indicate that leachate produced in the Seep 1 CKD Area does migrate into the regional groundwater, but is contained and diluted by the regional groundwater via the upward vertical hydraulic gradient.

The small area of saturated CKD described in Section 2.3.5.3 is located upgradient of a channelized section of the beach with approximately six feet of silt, sand, and gravel filling the bedrock channel. A preferential flow path for leachate generated from the saturated CKD exists as demonstrated by elevated pH levels observed in boreholes near the eastern extent of the Seep 1 IR beach collection drain.

Migration of shallow leachate and impacted deep regional groundwater to Lake Michigan is effectively mitigated by operation of the Seep 1 IR beach collection drains that intercept leachate flow adjacent to the shoreline. Capture of leachate flow in the Seep 1 East IR beach drain is enhanced by the augmentation vertical barrier wall. The vertical barrier was installed to address exceedances measured along the shoreline adjacent to the drain by cutting off the flow path in the unconsolidated material along the beach.

Leachate generated within the Seep 1 CKD pile does not migrate towards the municipal wells. This statement is supported by groundwater samples from the upgradient well nests for which no exceedances of pH have been observed. Monitoring and analytical data collected in east-unnamed creek #1 show that the creek has not been impacted by the Site. Based on the results of the Bay Harbor Lake Assessment, there are no signs that CKD or CKD leachate is present in or is currently impacting Bay Harbor Lake. The Bay Harbor Lake Assessment is included as Appendix 3-3 of the Development RI.

2.3.6.4 East CKD Area

Leachate migrates towards Lake Michigan and Village Harbor through the CKD pile and underlying soil. Regional groundwater migrating towards Lake Michigan has an upward hydraulic gradient and releases within close proximity of the shoreline. Groundwater pH exceedances are not evident in deep monitoring wells located adjacent to the Lake Michigan shoreline which suggests that leachate produced in the East CKD Area does infiltrate into the deep regional groundwater, but is contained and diluted by the regional groundwater via the upward vertical hydraulic gradient. The results of the Village Harbor geophysical investigation (Barr, 2006) conducted before IR actions, confirmed that leachate discharged nearshore based on conductivity measurements (see Figures 4-1, 4-2, and 4-3 in the Summary of Current Conditions/Work Plan for Village Harbor [Barr, 2006]). In March of 2007, the MDEQ completed an investigation through the ice cover along the East CKD Area to identify groundwater venting through preferential flow paths. The MDEQ conducted pH monitoring near the shoreline and further out in Lake Michigan. Based on the MDEQ data, the only locations to have pH that exceeded 9.0 were located along the shoreline which confirms that the leachate from the East CKD Area discharged diffusely nearshore. The MDEQ ice study is included as Appendix Q of the East CKD Area RI.

2.3.7 Leachate Discharge/Receptors

Leachate discharge and impacts to surface water in Lake Michigan and Village Harbor have been thoroughly investigated and documented. The observed leachate discharge zones are located nearshore, which is consistent with the expected regional discharge zone for groundwater beneath the Site as shown illustratively on Figure 2-4. The leachate discharge zones are shown illustratively on Figures 2-5, 2-6a, and 2-6b. These zones reflect the extent of surface water that has been observed to exceed pH 9.0 prior to IR action implementation. In general, the leachate discharge zones are located immediately downgradient (north) of the CKD piles (and west for the western side of East CKD Area).

Early indications of leachate discharge were identified along the Development Area shoreline where reddish-brown discoloration was observed. The MDEQ conducted investigations of the shoreline and documented pH measurements exceeding 12.0 in surface water. Subsequently, EPA conducted several monitoring and sampling events across the entire Site. pH impacts ranging from below 9.0 to 13.5 were observed in nearshore surface water at the Site. Analysis of water samples indicated elevated pH values and conductivity readings ranging from 2,200 to 7,800 µs/cm[2]. The samples showed elevated concentrations of aluminum, arsenic, copper, selenium, and vanadium. For example, the East Park-Seep1 sample from East CKD Area contained the following parameters: aluminum (4,700 µg/L), arsenic (32 µg/L), copper (6.3 µg/L), selenium (8.0 µg/L), and vanadium (170 µg/L). Mercury was not detected above the detection limit of 0.2 ug/L, but was later observed as high as 3.3 ng/L in surface water at the East CKD Area using low level mercury analysis procedures (see Table 2 of the East CKD Area AE). Summaries of the MDEQ and EPA investigations are included in the Work Plan (Barr, 2005).

The location and resulting impacts from leachate discharge in Lake Michigan and Village Harbor have been further validated by lakeshore monitoring data, including Targeted Shoreline Surveys and surface water quality analyses. This work is discussed in detail in the East CKD Area and Development Area RI Reports. Additionally, results from the MDEQ ice study at East CKD Area (see Appendix Q of the East CKD RI) confirmed that leachate impacts were nearshore (SL samples);

investigation lines A and C, which were about 350 feet and 500 feet off the shoreline, did not contain observable leachate impacts.

The Federal Agency for Toxic Substances and Disease Registry (ATSDR) and Michigan Department of Community Health Department (MDCH) cooperatively conducted a public health assessment as the result of the high pH seep observance at the Site. These entities concluded that the high pH levels in pools along the shoreline posed a public health hazard as direct exposure may result in irritation of eyes, skin and mucous membranes and that exposure to water at pH greater than 11.5 may result in irreversible damage to these tissues. Additionally, mercury levels detected in the seep discharge posed a public health hazard as mercury is a bioaccumulative chemical that has been found in Lake Michigan fish at levels that could produce human health effects. This assessment is included as Appendix V of the East CKD Area RI (Barr, 2009).

Expedited removal actions were implemented immediately to address the risk of exposure to high pH pools on the shoreline in spring 2005. Collection drains were installed along the shoreline congruent with the observed leachate discharge zones to intercept the leachate prior to discharge to Lake Michigan as discussed in Section 2.5, Completed Remedial Actions. Data from the Seep 1 collection drain provides good example of the ability of these drains to intercept mercury contaminated groundwater; mercury concentrations measured in the Seep 1 IR valve boxes during the March, June, and August 2007 sampling events ranged from approximately 122 to 193 ng/L. The collection drains and other completed IR actions have been highly effective in mitigating high pH exceedances and drastically improving water quality in the Lake. As discussed in Section 2.5 and Section 3.0, implementation of the IR actions at the East CKD Area have resulted in no pH exceedances in surface water in 2009, greater than 90% surface water quality improvement and mercury flux reduction based on the latest round of mercury flux evaluation. As a result of these efforts, public health officials downgraded the Public Health Advisory on June 18, 2009. The Public Health Advisory now takes the form of a notification at the Park and does not restrict access or contact with the water (see http://www.nwhealth.org/News%20Releases/NR%20East%20Park.html).

2.4 Restoration Potential

The following sections provide an evaluation of the restoration potential of the Site, including data and analyses that demonstrate the achievement of the GSI criterion for 1.3 ng/L is technically impracticable from an engineering perspective. Specifically, that the criterion cannot be achieved through complete source removal or complete isolation and containment, or any other remedial technologies, due to insurmountable challenges such as the inevitability of residuals and the hydrogeologic setting (fractured bedrock aquifer). This section also evaluates the potential for treating Site leachate to below the GLI criterion of 1.3 ng/L.

Though the criterion cannot be fully achieved, remedial measures that focus on mercury mass reduction to the Lake can be implemented. The completed remedial actions provide advancement toward achieving significant mass reduction as discussed below, and additional measures contemplated for the ARS (see Section 3.0) will further reduce mercury mass loading.

2.4.1 Complete Removal

In theory, complete removal is the removal of all CKD from the entirety of the Development and East CKD Areas. This equates to over two million CY of CKD that would be transported via truck to a RCRA Subtitle D landfill for disposal as non-hazardous waste. Complete removal would provide a reduction in long-term mercury mass flux from the Site; however, this activity would come at the expense of near-term protection of human health and the environment. Specifically, the near-term impacts associated with exposing a large quantity of CKD for an extended duration and the transportation risks associated with relocating the waste.

Regardless of the implementation challenges and despite the long-term mercury mass reduction, complete removal is incapable of providing full restoration of the impacted groundwater to the GSI criterion in a reasonable timeframe. The technical impracticability of complete removal stems from the geologic and hydrogeologic setting at the Site. Specifically, there are insurmountable physical implementation challenges associated with CKD entrainment within the fractured bedrock and the presence of saturated CKD. Complete removal is shown in a conceptual cross-section on Figure 2-9.

Complete removal of all source material (CKD) is infeasible because:

- all technologies available for the removal of solids from beneath the water (i.e. dredging equipment) at the scale contemplated for the Site are not capable of removing 100 percent of the solid material,
- saturated CKD can behave similar to a low-strength, somewhat flowable gel-like mixture (Todres, et al., 1992a and 1992b), which can cause significant material handling issues, and
- the huge volume of dewatering water that would be necessary to facilitate removal of CKD without dredging (which could potentially help to minimize, but not fully eliminate any residuals) cannot be managed.

Because complete removal cannot effectively remove all the source material, some residual CKD would remain at the Site, continuing to release mercury above the GSI criterion for decades, conceivably 100 years or more. It would be expected that groundwater at the Development and East CKD Areas would continue to exceed the GSI criterion. Thus, the substantial effort of attempting complete CKD removal would not comparatively provide any additional protection of human health or the environment with regard to the proposed ARS, which includes targeted removal that is practicable (see Section 3.0). The viability of partial/targeted removal of CKD from the Site is discussed in further detail the East CKD and Development AEs.

The following subsections further describe the limitations of available dredging and excavation equipment as they pertain to CKD removal.

2.4.1.1 Residuals from Dredging Operations

Because portions of the CKD piles are below groundwater, removal must be either by dredging techniques or with dewatering. This section explains the limitations of dredging technologies. Dredging technologies to remove contaminants from the environment (i.e. environmental dredging) have improved significantly in the past decade. Some of these improvements include:

- mechanical modifications to cutter-heads for hydraulic dredging operations that minimize the portion of material that is disturbed by the cutter head but not transported to the suction line;
- redesign of clam-shell buckets to help retain material as it is removed from the subsurface; and
- quality control procedures to monitor the progress of conventional sub-aqueous excavation operations.

However, even with these improvements, it is generally understood that environmental dredging will always have some ‘residual’ material that can not be removed. The issue of residuals management has been a topic of many publications by the U.S. Army Corps of Engineers and others within the dredging community (Bridges, et al., 2008). This collection of experts concluded that it is not feasible to remove all of the solid media in any environmental dredging operation due to both the physical limitations of the equipment and the nature of environmental sites (e.g., obstacles to removal equipment, geologic features).

Typical residual mass estimates range from four to seven percent. However, residuals may be higher than ten percent in particularly difficult environments (Desrosiers and Patmont, 2009).

Even a small volume of residual CKD is likely to have significant long-term impact on groundwater quality for decades after incomplete source removal. The West CKD Area (which is the smallest of the piles) can be used to illustrate this concept. An estimate of mercury remaining post-excavation (assuming 5% residuals) and the minimum time for the mass of residual mercury in CKD to leach was developed. The total mass of mercury remaining post-excavation is greater than 500 grams. If the removal efficiencies are less (i.e. higher residuals), then the mass of mercury remaining will be even greater. A conservative estimate of the time needed to leach all of the mercury from the residual CKD to a groundwater concentration that would not exceed the GSI criterion ranges from a minimum of 25 years to potentially much greater than 50 years. The most conservative estimate is based upon the assumption that mercury concentrations in groundwater come into equilibrium with the concentrations in the CKD at a distribution s similar to those observed currently in the groundwater with no hindrances. If the rate of desorption is slower, then the time for the concentration of mercury in groundwater to be reduced to the GSI criterion could be much longer.

2.4.1.2 Limitations to Conventional Excavation

Conventional excavation of the source material, in particular the material below the water table, is not practical because it cannot be accomplished in a reasonable time frame without dewatering. In addition, dewatering would generate a significant volume of water which could not be discharged to Lake Michigan due to GLI restrictions without a waiver of this ARAR. Source removal has been included in the East CKD Area and Development Area AEs for the Site. Some of the important reasons for the infeasibility of source removal, either with limited dewatering or with a conventional dewatering operation, are discussed in more detail below.

Subaqueous Removal

Without dewatering, conventional excavation of the source material below the water table would resemble the dredging operations described in the previous subsection. Excavation would need to be completed using a barge-mounted excavator, which would need to be continually repositioned to load trucks for off-site transportation and disposal. The rates of production that could be achieved for conventional excavation below the water table would be on the order of 1,000 CY per day, which is similar to the rate achieved during the targeted removal for the East CKD Area. Production rates for conventional excavation above the water table could be on the order of 2,000 CY per day. For a potential removal volume of 2,000,000 CY, and assuming the viable construction season is about 200 days and production rates are as discussed above, over six years would be needed to complete the excavation.

During the period when the excavation is open, water would be generated from precipitation, dewatering of the excavation, as well as the existing leachate collection system. Excavation in the saturated zone breaks up wet CKD and mixes it; effectively accelerating mineral hydration reactions in the CKD. Excavation also exposes previously covered non-weathered and unsaturated CKD to precipitation which will add to the leachate that must be managed. This agitation of CKD during subaqeous removal would result in the discharge of very high pH and mercury laden leachate to the lake without exorbitant rates of collection. The targeted removal at the ‘bottleneck’ provides good example of the short-term impacts associated with a removal action, despite the effective dewatering of the excavation to facilitate removal and backfill. The removal was completed in early September 2006 and nearshore surface water quality initially spiked to above pH 11 in some areas, and did not consistently improve to below pH 9 for three months.

During backfilling operations, water may need to be removed at the rate that fill is being placed to allow for adequate compaction. For an approximate fill rate of 1,000 CY per day, the volume of water that may need to be treated during backfill placement would exceed 200,000 gallons per day (150 gpm) for an approximate backfill rate of 1,000 CY per day. For perspective, the proposed diversion system at the East CKD Area, which will divert the practicable amount of upgradient groundwater from contacting CKD, is anticipated to operate in the range of 120 gpm. This would be near the minimum amount of water that would be expected to be generated because it does not account for additional pumping to lower the water table below the excavation base or any precipitation derived water.

The excavation water would be laden with CKD solids which would require pretreatment prior to neutralization or other treatments prior to disposal. For example, flocculation and filtration phases to remove suspended solids were implemented during the ‘bottleneck’ removal at East CKD Area to address the excessive suspended solids. The pretreatment train included pumping into an equalization tank, followed by addition of a flocculation aid and settling in a clarifier tank, followed by pumping through progressively smaller effective opening filter bags, prior to neutralization and load-out for transfer to an offsite injection well.

Despite the potentially large volumes and onerous sediments management that would be required, management of as little as 200,000 gallons per day (and likely more to account for lowering of the water table and precipitation, and more for conventional dewatering) is not feasible without a waiver of the GLI mercury discharge standards because the potentially available alternatives to discharging the water – including spray fields, injection wells, or POTWs would not be able to handle this volume of flow.

After the source removal has been completed additional leachate collection would still need to be continued for many years into the future to manage the mercury in leachate from residual materials that could not be removed using sub-aqueous excavation techniques.

Conventional Excavation with Dewatering

The alternative to subaqueous excavation would be to dewater the excavation, allowing removal equipment and trucks to enter the work zone and allow the placement of fill. Conventional excavation removal rates would allow for all of the CKD to be removed from the Site in approximately five construction seasons. However, it would still face limitations in removing the source material, especially in areas of uneven bedrock surfaces. The geology at the Site is considered unfavorable to complete removal of CKD. It is not possible to remove CKD entrained in weathered bedrock and bedrock fractures.

Dewatering would need to collect storm water and would also necessarily collect the water in and near the CKD to dewater the area of the excavation. The water with the most contact to the CKD is likely to have the highest concentrations of dissolved solids and mercury. Excavation, dewatering, and dust control best management practices are expected to increase the quantity and worsen the quality of leachate during removal activities.

A dewatering operation would pump significantly more water than was generated during the targeted removal of source material from the East CKD Area (approximately 6,600 gallons per day). For example, a preliminary estimate of dewatering flow that may be needed to remove all the saturated CKD at East CKD area is approximately 1,440,000 gallons per day (1,000 gpm) (Barr, 2009d). This estimate assumed that a limited area of the excavation would be dewatered to allow removal and that the dewatering equipment would be repositioned as the excavation proceeded. As with the potential volume of water generated during backfilling operations for a subaqueous removal, this volume is again considerably more than could be managed using technologies other than discharge to the lake with a waiver of the GLI criteria for mercury.

As with the other removal alternatives, residual CKD, and therefore leachate, would remain at the conclusion of a complete removal operation that would need to be collected and removed for off-site disposal if a waiver of the GLI mercury standard is not obtained.

2.4.2 Complete On-site Containment of CKD

In theory, complete containment of the CKD piles would “entomb” all CKD from the entirety of the East CKD and Development Areas. This equates to the handling of over 2,000,000 CY of CKD. CKD would be backfilled above the water table in an impermeable liner and cover system, minimizing leachate generation by placing barriers to sources of water to the pile (e.g., from any precipitation, infiltration, subsurface run-on, etc.). This concept is shown in Figure 2-10. CKD that could not reasonably be consolidated on-site within an acceptable footprint and grade would be transported via truck to a RCRA Subtitle D landfill for disposal as non-hazardous waste. Complete containment would provide a substantial reduction in long-term mercury mass flux from the Site, however, this activity would come at the expense of other considerations with regard to protection of human health and the environment, namely the short-term impacts associated with exposing such a large quantity of CKD for an extended duration and transportation risks associated with relocating the waste (e.g., traffic dangers for nearby residents, increased truck traffic through the City of Petoskey).

Consistent with complete removal, complete containment is incapable of providing full restoration of the contaminated groundwater to the GSI standard in a reasonable timeframe due to residual CKD that would remain beneath the on-site containment cell, an outcome associated with the practicality of removal methods and site-specific features, namely the geologic (fractured bedrock) setting at the Site. The substantial effort of source containment would not comparatively provide any additional protection of human health or the environment with regard to complete removal over the proposed ARS (see Section 3.0). Nor would source containment eliminate the need for an ARAR waiver for mercury treatment, specifically during the removal activity when CKD impacted water generation rates would exceed any off-site disposal facility capacities. Additionally, on-site containment poses risks to human health and the environment beyond complete removal since some of the CKD would remain on-site in an engineered facility that is subject to construction imperfections that allow on-going leachate production as well as the more remote potential for breach or leakage.

Complete containment would also require the removal of existing remedial system infrastructure that has been constructed at the Site, which is in conflict with the stated intent of the National Oil and Hazardous Substances Pollution Contingency Plan (NCP) which requires interim remedial actions be integrated into the final remedy (or ARS) to the extent practicable. This potential conflict is particularly evident at the East CKD Area where CKD has been consolidated and graded and an impermeable cap has been installed over the entirety of the remaining CKD footprint.

2.4.3 Complete Collection of CKD Leachate

In theory, complete collection of leachate and leachate-impacted groundwater (mixture of leachate and groundwater) with engineered solutions would achieve full capture of the leachate plume. In concept, this would include the installation of measures which would collect all of the leachate impacted groundwater at the Site (i.e., all potentially impacted groundwater down to elevation 480 ft. MSL at the East CKD Area and to elevation 400 ft. MSL at the Development Area).

In reality, however, this concept is technically impracticable due to the hydrogeologic setting of the Site. Specifically, there are insurmountable physical implementation challenges associated with the fractured bedrock media and the proximity of the waste source to the lake. The depth of the bottom of the plume renders collection trenches incapable of capturing all groundwater with mercury impacts above 1.3 ng/L, thus prompting the use of pumping wells. Pumping wells in fractured bedrock aquifers can have widely different sustainable pumping rates and capture zones due to the generally heterogeneous and anisotropic nature of fractured rock aquifers. As a result, complete capture cannot be guaranteed unless the wells extend to the bottom of the plume and pump an exorbitant amount of water.

An illustration of a large pumping well is shown on Figure 2-11 The challenges associated with implementation of this concept are provided in more detail below for the two areas.

2.4.3.1 East CKD Area

As noted above, complete capture of impacted groundwater in the East CKD Area would require capture down to an elevation of approximately 480 feet MSL. Theoretically, groundwater capture could be achieved via collection trenches at the current downgradient perimeter (near shoreline area) of the CKD pile, pumping wells upgradient of the CKD pile or pumping wells within the footprint of the CKD pile. In practice, there are significant technical challenges associated with each of the theoretical capture system options.

In order to ensure capture down to the target elevation, collection trenches along the downgradient perimeter of the CKD pile would need to be significantly deeper than the existing IR drains. Due to the proximity to both Lake Michigan (including Village Harbor) and the CKD pile, the presence of limestone bedrock, and the limited trenching depth of commercially available rock trenchers, construction of significantly deeper trenches to depths adequate for full collection is not feasible.

Installation of a barrier between Lake Michigan (including Village Harbor) and the collection system would likely be necessary to limit the collection of lake water in this system. Such a barrier would need to be significantly deeper than the barrier associated with the existing IR drain on the west side of the East CKD Area. Similar to trench construction, construction of such a barrier is not feasible.

A potential option for collecting deeper water would be a series of pumping wells upgradient of the East CKD Area or within the East CKD pile. The proximity of the East CKD Area to Lake Michigan would likely require a series of pumping wells to have a combined pumping rate of thousands of gallons per minute in order to ensure complete groundwater capture to the target elevation. This conclusion is supported by the results of a pumping test conducted in the East CKD Area during the remedial investigation (Barr, 2009c). Pumping from a series of high capacity wells would result in a reversal of the regional hydraulic gradient beneath the Site such that water would be drawn from Lake Michigan to the wells. Due to the proximity of the CKD pile to Lake Michigan, the gradient reversal would result in water from the lake flowing through some portions of the CKD pile on the way to the pumping wells thereby creating more leachate. The volume of water that would require disposal would be orders of magnitude larger than the volume currently collected by the existing IR drains. In addition, a system of high capacity pumping wells would likely suffer from significant well interference and could also have a negative impact on nearby private wells. The well interference could be exacerbated by the need for multiple wells to ensure an adequate radius of capture, given that some portions of the fractured bedrock aquifer may have relatively low yield.

Any system designed to ensure complete groundwater capture down to the target elevation would also inevitably capture deep groundwater unimpacted by the plume. Capture of the unimpacted groundwater would result in dilution of the impacted plume water. It is possible that the collected water could contain a concentration of mercury below the 1.3 ng/L criterion if enough unimpacted groundwater is captured. However, on a mercury mass flux basis, the discharge water would likely contain mercury at levels at or above current mass discharge rates due to the significant volumetric flow rates. Assuming the discharge rate would be 1,000 gpm and the mercury concentration would be 1.3 ng/L, the discharge mercury mass flux would be about 7 mg/day, which is close to the existing IR mercury mass flux rate and twice the estimated flux rate for the ARS (see Table 3-1). Since the only practicable discharge option for the large volumes of water that would be collected would be to discharge the water to Lake Michigan, the intended outcome of reducing mercury mass flux to the lake would not be obtained. On the other hand, if the collected water contained mercury concentrations above 1.3 ng/L, it could not be treated to achieve the 1.3 ng/L GLI criterion because low concentrations of mercury are virtually untreatable with best available treatment technologies as discussed in Section 2.4.6.

2.4.3.2 Development Area

As noted above, complete capture of leachate in the Development Area would require capture down to an elevation of approximately 400 feet MSL. In addition, any system for complete capture would need to have a component to address perched groundwater like that present in the Pine Court seep subarea (see SCM Section 2.3.6.2) in addition to the deeper regional groundwater. Theoretically, regional groundwater capture to the target elevations could be achieved via collection trenches and/or pumping wells downgradient of the CKD piles in the near shoreline area, pumping wells within the footprint of the CKD piles, or pumping wells upgradient of the CKD piles. Consistent with the East CKD Area, however, there are significant challenges associated with each of the theoretical capture system options, including the collection of exorbitant amounts of water (deep unimpacted groundwater and lake water), well interference and logistical constraints, and water management issues (either accelerated mass loading to the lake via diluted discharge or by treatability constraints that cannot reliably or consistently achieve 1.3 ng/L). An additional complicating factor at the Development Area is the presence of City of Petoskey municipal pumping wells. As discussed above, available groundwater elevation data indicates that seasonally high pumping in the municipal wells, particularly City Well 5, affects groundwater elevations and groundwater hydraulic gradients in parts of the Development Area. City Well 5 pumps on the order of approximately 1,000 gpm. This provides some relative measure of the amount of collection that may be necessary to ensure capture, but inevitably provides a conflict as the municipal pumping well and the collection pumping system would be in competition. Well interference would result in a reduction of capacity for both the municipal well and the collection system wells, especially during peak pumping periods such as summer.

2.4.4 Complete Hydraulic Containment

In theory, complete hydraulic containment would achieve hydraulic control over the leachate plume (i.e., prevent movement of the plume toward Lake Michigan by controlling the hydraulic gradient) with engineered solutions. In concept, this would include the installation of measures which would fully isolate the plume hydraulically, such as a deep “moat” or series of upgradient pumping wells that would create a flat hydraulic gradient under the footprints of the CKD piles at all times. The result would be that the plume would not discharge to the lake. In practice, a 100% flat hydraulic gradient cannot be attained. An illustration of a conceptual hydraulic containment system is shown on Figure 2-12.

Hydraulic containment is technically impracticable due to the hydrogeologic setting at the Site. In either the East CKD or Development Area, a complete hydraulic containment system would be constructed upgradient of the CKD pile(s). In order to maintain complete hydraulic containment, the system would have to be constructed in a manner that would allow the hydraulic head along the system alignment to be maintained at the same elevation as the water elevation in Lake Michigan. Due to the elevation of the limestone bedrock and the limited trenching depth of commercially available rock trenchers, the construction of a “moat” of sufficient depth to maintain complete hydraulic containment is infeasible without a massive subcut to provide a suitable trenching pad. Performing such enormous amounts of earthwork without the benefit of addressing the source material renders this approach impracticable.

While installing high capacity pumping wells is possible, the infeasibility of controlling the hydraulic gradient with these wells was communicated previously to the U.S. EPA (CMS, 2007). In addition to the well interference issues discussed above, fluctuations in groundwater and lake elevations, shoreline geometry, variable rates of regional groundwater withdrawal, and the proximity of the Site to the regional discharge zone would make it impossible to operate a pumping system in a manner that would ensure that the hydraulic gradient would be maintained at zero at all times and that leachate would never discharge to Lake Michigan. Development Area groundwater elevation data and municipal well pumping records suggest that a pumping system designed to maintain a zero hydraulic gradient would need to have a pumping rate of well over 1,000 gallons per minute. The only practicable discharge option for the large volumes of water that would be collected would be to discharge the water to Lake Michigan. Since the hydraulic gradient could not be maintained at zero at all times, an inward gradient toward the pumping wells would be necessary to fully contain the plume. Thus, it is likely that CKD leachate would be drawn into the pumping wells. The discharge water may contain mercury concentrations and have high enough flow rates that the flux of mercury to the lake would actually increase. As a result, the intended outcome of reducing mercury mass flux to the lake would not be obtained, and could potentially be exacerbated. On the other hand, if the collected water contained mercury concentrations above 1.3 ng/L, it could not be practicably treated to achieve the 1.3 ng/L standard as low concentrations of mercury are exceedingly difficult to remove with best available treatment technologies as discussed in Section 2.4.6. As a result, there would be no guarantee that the collected water would meet GLI discharge requirements and an ARAR waiver would be necessary for discharge to the lake.

2.4.5 Other Remedial Technologies

No remedial technologies have been identified that could achieve complete groundwater restoration at the Site to mercury concentrations reliably and consistently below 1.3 ng/L in a reasonable timeframe. The technologies presented and discussed in previous subsections: complete removal, collection, and containment have been developed in the AEs and are based on review of the technical literature, specifically pertaining to CKD waste. However, these and all of the other remedial technologies reviewed, singly or in combination, would not provide restoration of the aquifer to below 1.3 ng/L. Not even complete removal, which has been demonstrated to be impracticable, can be counted on to achieve this criterion.

Innovative technologies, such as in situ treatment of CKD with Accelerated Carbonation Technology (ACT), for example, have been identified for potential stabilization of CKD, thus resulting in eventual aqueous plume restoration. This and other technologies were determined to be impracticable with regard to general Site conditions and with regard to Site specific geologic, hydrogeologic, and contaminant-related settings.

2.4.6 Leachate Management

A significant complication to the development of viable remedial actions to achieve aquifer restoration to 1.3 ng/L is leachate management. Any conceivable potential alternative to achieve the criterion would include collection of enormous quantities of leachate (i.e., several hundreds to thousands of gpm). This provides an insurmountable challenge when the quantity of leachate exceeds practicable off-site disposal facility capacities and water quality requirements. The impracticability of off-site disposal of large volumes of CKD impacted leachate is described below in Section 2.4.6.1. The viability of off-site disposal for management of ARS anticipated flowrates is discussed in the East CKD Area and Development Area AEs.

On-site treatment and direct discharge to surface water near the Site is the only viable option for large quantities of leachate. But the viability of this option is dependent upon the ability to permit the discharge and to treat the water to an appropriate discharge concentration. For permit able discharges to surface water, the concentration of mercury at the pipe outlet would need to comply with the GLI criterion of 1.3 ng/L. Water treatment technologies that remove mercury from water to concentrations below the GLI water quality standard of 1.3 ng/L are not available, rendering this option impracticable without a waiver of the GLI criteria for the discharge. The impracticability of treating water with mercury to the low GLI criterion is discussed in Section 2.4.6.2.

2.4.6.1 Off-site disposal options

Several off-site disposal options exist for leachate. However, these options have capacity and water quality requirements that preclude the disposal of large volumes of leachate. Off-site disposal options for leachate have been reviewed in the AEs and include the following:

a) On-site pretreatment (as necessary) and disposal to an off-site publicly owned treatment works (POTW) for treatment and discharge to surface water via an existing NPDES permit.

b) Off-site disposal using deep well injection (this discussion also applies to on-site deep well injection)

c) Off-site land application of collected leachate.

d) Evaporation of leachate using off-site evaporation ponds.

POTW

This option consists of the pretreatment of leachate, as necessary, and disposal to a POTW (e.g., City of Petoskey or Traverse City). The ability of a POTW to accept leachate from the East CKD and Development Areas is dependent on several factors including: total volume of flow, temperature of the water, organic loading, total dissolved solids loading, and total mercury loading. The current City of Petoskey POTW has a treatment capacity of 2.5 million gallons per day (MGD) (see http://www.ci.petoskey.mi.us/uploaded_files/Chapter_3_Community_Utilities,_Facilities_and_Services_FINAL.pdf).

Potential flows of thousands of gallons per minute would be necessary for full collection/hydraulic containment as discussed in Section 2.4.2. One thousand gpm is equivalent to about 1.5 MGD, or roughly 60 percent of the current City of Petoskey treatment capacity. Dedicating this capacity to the treatment of leachate is not tenable for the City of Petoskey. An additional, and potentially more significant limitation for this disposal approach, is the lack of infrastructure and the lack of a legally assessable corridor to get the leachate to the POTW. The existing infrastructure between the site and the POTW is not sized for a point discharge of this magnitude. The capacity of the current City of Petoskey POTW and conveyance infrastructure renders this option impracticable for large volumes.

Trucking leachate to a POTW, or other locations for off-site disposal, would be intensive and poses significant concerns related to traffic congestion and general public safety. Each tanker truck carries approximately 11,500 gallons. To transport 1.5 MGD, 125 truck loads would travel local roadways daily.

Deep Well Injection

This option consists of pretreatment of the leachate, transport to a disposal well, and disposal by injection into a geologic formation with no potential for cross contamination of potable water aquifers. A typical injection well is double cased and extends several thousand feet below ground level into a permeable injection zone that is saline and confined vertically by nearly impermeable strata. The outermost casing extends below the base of any underground sources of drinking water and is sealed to prevent contamination of nearby aquifers. Deep well injection is engineered to prevent impacts to surface water or groundwater.

The capacities of deep injection wells vary, but a reasonable capacity assumption is approximately 200,000 gallons per day. Seven exclusively dedicated deep injection wells would be necessary to accommodate 1.5 MGD based on this assumption. Only one active commercial Class I industrial injection well was identified on the U.S. EPA website in the northern lower peninsula of Michigan (http://www.epa.gov/r5water/uic/cl1sites.htm#mi_active). Identification, siting, permitting, and construction of seven or more deep injection wells render this option impracticable for large volumes.

Land Application

Land application of solids and aqueous residuals is a treatment alternative used by industrial and municipal waste water treatment plants. The treatment process uses spray applicators to distribute the waste stream onto the land surface where the water as well as the contaminants are absorbed by surface plant material or adhered to and attenuated by soils. MDEQ guidance for load application limits the volume of water applied over the application area to 40 inches per year. This equates to approximately 1 million gallons per acre per year.

The minimum acreage required to accommodate 1.5 MGD is 550 acres. However, the more significant consideration for this disposal option is the necessary storage capacity to hold leachate during non-growing periods. Assuming that land application could not be performed four months out of the year, a total storage capacity of over 180 million gallons would be required. To store this volume of leachate, 20 ten million gallon tanks and associated secondary containment would be required, consuming over 20 acres of land. The enormous amount of land that would be consumed by spray irrigation and storage renders this option impracticable for large volumes.

Evaporation Pond

Evaporation/settling ponds have been used for the management of aqueous waste streams where separation of solids can be facilitated. This disposal alternative uses lined ponds from which the leachate would eventually evaporate and remaining solid residuals would be removed and disposed of in a permitted landfill.

Near the Site, natural evaporation processes are not favored due to moisture saturation of air close to Lake Michigan, annual precipitation that exceeds annual evaporation, and relatively low average temperatures. Review of the literature regarding water balances in northern lower Michigan demonstrate that precipitation exceeds evaporation on an annual basis by approximately 11 inches (31 inches of precipitation and 20 inches of evaporation) as discussed in Section 4.3.2.3 of the Development RI. Thus, leading to annual increase in pond area to accommodate the waste stream and rendering this option impracticable. Other considerations are lack of natural settling ability for leachate and the need for energy assisted evaporation which would generate greenhouse gases and incur exorbitant costs.

2.4.6.2 On-site treatment and discharge

Water treatment technologies that remove mercury from water to concentrations below the GLI water quality standard of 1.3 ng/L on a reliable and consistent basis are not available. There are limited examples of evolving technologies that have been demonstrated at the bench or pilot level to achieve low concentrations of effluent mercury, however, there are no demonstrated technologies that have been applied at full-scale specifically for removal of mercury to 1.3 ng/L. While some existing systems have shown the ability to remove mercury to very low levels – for example some municipal wastewater treatment systems – this is not the primary function of the treatment operation and their effectiveness at mercury removal may not be reliable for treatment of Site leachate.

There are, however, water treatment technologies commercially available that can remove mercury reliably and consistently to concentrations in the range of 20 to 30 ng/L which can result in significant mercury concentration reductions. Collected leachate at the Site contains mercury up to concentrations as high as 700 ng/L. Reduction to the achievable concentrations would result in as high as 95% reduction in mercury concentration for Site leachate. Removal of mercury to below concentrations of 20 to 30 ng/L is exceedingly difficult and impracticable.

The ability to remove mercury in water treatment processes to the very low concentrations mandated by the GLI is exceedingly difficult because mercury can be present in multiple physiochemical states and the presence of other water quality constituents can provide competition for treatment effectiveness:

- Mercury is rarely the dominant dissolved constituent in the water – the ions that dominate water chemistry will have a greater impact on the applicability and effectiveness of any particular treatment technology that could be considered for mercury. Generally, other constituents affecting water quality need to be addressed before considering mercury removal.

- Mercury in aqueous solution is capable of complexing with many different ions to form stable compounds – the variety of potential complexes result in mercury treatment technologies needing to be either broad enough to deal with many different forms of mercury complexation or focused on a single mercury complex. While it is generally very difficult to develop a technology that works well on many different forms of a particular chemical, any technology that focuses on a single form of chemical complex will have limited applicability.

Treatment technologies for the removal of mercury from water have been evaluated at numerous facilities across the United States and at the Site. These technologies have been demonstrated to be able to remove a significant percentage of mercury from various wastewater streams – including groundwater, and municipal and industrial wastewaters – but none have demonstrated a final, sustained effluent concentration below the GLI water quality standard.

The identification and development of treatment technologies capable of removing mercury from water to concentrations that would meet the GLI water quality standard has not suffered from a lack of attention. Numerous research programs have been developed to attempt to achieve the treatment goals for mercury. The following paragraphs provide an overview of the nature of mercury in aqueous solutions and the treatment technologies that have been evaluated and published in the literature from the U.S. EPA, the Site, and others to evaluate the removal of mercury from water and wastewater.

Mercury in Aqueous Solution

The most common forms of mercury in soil, water, and sediment are inorganic mercuric salts such as HgS, $HgCl_2$, $Hg(OH)_2$, and organomercuric compounds such as methyl mercury ion ($CH3Hg^+$), methyl mercury chloride (CH_3HgCl), and methyl mercury hydroxide (CH_3HgOH) (U.S. EPA, 1997). The original form of mercury in CKD at the Site is likely inorganic because the temperatures used to produce cement oxidize most organic matter.

When water contacts the CKD, some of the mercury will dissolve into the water. Mercury can be present in water in many forms including:

- Inorganic mercury (charged mercurous (Hg^{1+})or mercuric (Hg^{2+}) ion, uncharged metal (Hg^0)),
- organomercuric compounds,
- stable ionic complexes with chloride, sulfate, or dissolved organic matter, and
- bound or incorporated into suspended solid materials.

For CKD, ionic mercury dissolution, into the water will form stable, soluble complexes with the other ions, most notably chloride, sulfate, and dissolved organic compounds. The high pH of the leachate may also result in the formation of stable complexes of mercury hydroxide. Thus, the dissolved mercury in solution is likely in the complex form. Organomercury (primarily methyl mercury, which is the basis for the GLI standard) may also be present because mercury, sulfate and organic matter are present in an anaerobic environment that could support sulfate reducing bacteria, which methylate mercury to prevent toxicity. However, the elevated pH in the core of the leachate plume likely limits microbial sulfate reducing activity to the fringes of the leachate plume.

The variety of potential physiochemical states for mercury in the environment makes it difficult to remediate or remove using a single technology, in part because the physical and chemical properties (e.g. aqueous solubility, density, melting points and boiling points) of each form vary widely. Additionally, the inorganic forms of mercury are known to form complexes with soils, colloids, and dissolved organic compounds, which influence the mobility of mercury in the environment (U.S. EPA, 1997) and this tendency to form complexes also has implications for treatment. The end result is that mercury speciation and the chemistry of the surrounding environment influence the behavior of mercury to such a degree that each mercury removal application is potentially unique.

U.S. EPA Mercury Treatment Research

In 2007 the U.S. EPA published a review of information available concerning treatment technologies for removal of mercury from water (U.S. EPA, 2007). Information was available on the pilot-scale or full-scale level for several treatment technologies including:

- Precipitation/coprecipitation,

- Adsorption,
- Membrane Filtration, and
- Biological Treatment

Chemical precipitation is similar to the operation that was pilot tested at the Site (see below). Some of the work, however, included multiple chemical additions and precipitation steps in sequence to improve mercury removal performance. The most common chemical additive used to remove mercury was sulfide, or complexes containing a sulfide group – such as the proprietary metal precipitating reagent investigated at the Site. Other chemicals were also used to control pH and assist with the coagulation and flocculation of the precipitates formed.

Adsorption relies on the affinity of a solute for a solid surface, such as activated carbon. Because the performance of this technology is affected by other chemical constituents in the water, it is best applied to waters with relatively low concentrations of other dissolved constituents. The authors indicated that adsorption can only be considered a polishing step in a multi-process treatment train for mercury removal.

Membrane filtration can include either physical removal of solid particles or chemical separation of dissolved ionic species in the water. Microfiltration and ultrafiltration remove solid particles while nanofiltration and reverse osmosis both remove dissolved ions. Because mercury may be present attached to suspended solids and dissolved in solution, a combination of membrane treatment technologies may be needed to effectively remove total mercury. Membrane filtration, like adsorption, also has the potential to serve as a secondary treatment step, for example after chemical precipitation, in a mercury removal treatment train; but it is not appropriate as the primary treatment step. As noted in the U.S. EPA report, the one full-scale system that used ultrafiltration as a secondary treatment process was capable of reducing the effluent mercury concentration to only below 400 μg/L. No reports for the potential removal efficiency of nanofiltration or reverse osmosis membranes for mercury removal were included in the U.S. EPA literature study.

Biological treatment is commonly used in municipal wastewater treatment plants to remove carbonaceous materials that, if discharged to the environment, would result in unacceptable consumption of dissolved oxygen in the receiving water. Many biological treatment plants also remove nutrients that have the potential to accelerate the eutrophication of the receiving water. Most conventional biological treatment plants include primary treatment of suspended materials followed by secondary treatment where microorganisms are used to consume the carbonaceous material and nutrients in a controlled, accelerated fashion. Both the physical settling process and the biological growth process have the potential to remove mercury. In particular, it is thought that the growth of microorganisms creates potential surfaces where mercury can be adsorbed and ultimately removed from solution.

A summary of the lowest mercury effluent concentrations identified in the U.S. EPA literature study for each treatment process is summarized in Table 2-4. None of the studies researched achieved an effluent concentration of mercury of 1.3 ng/L or less.

While biological systems have the potential to remove mercury from solution, the overall effectiveness of biological removal mechanisms is often limited by the solids removal and settling processes employed in these facilities. For example, the allowable discharge limits for suspended solids from conventional wastewater treatment facilities is typically between 10 and 30 mg/L, which is six orders of magnitude greater than the GLI standard for mercury. Thus, a concentration of mercury on the residual solids of as low as 1 mg/Kg would result in exceedances of the GLI limit for mercury.

In addition to the technologies evaluated at pilot-scale or full-scale, the authors identified two other technologies that are innovative and being considered for removing mercury from water. These include:

- Nanotechnology – this process would include the placement of nano-scale adsorptive surfaces on adsorbent media. One such material is thiol self-assembled monolayers on mesoporous silica (Thiol-SAMMS). This technology is being developed and commercialized by Pacific Northwest National Laboratory. Of particular promise is the high affinity of Thiol-SAMMS for mercury and the lack of interference on adsorption by chlorides and organic matter (Pacific Northwest National Laboratory, 2009). In at least one bench-scale application, treatment of water to a achieve reduction in total mercury from 4.5 to 0.7 ng/L was reported (Pacific Northwest National Laboratory, 2009).

- Air Stripping – this process would include the reduction of dissolved mercury, followed by air stripping. Mercury vapor could then be collected to contain the mercury. An example of this treatment process has been demonstrated using stannous chloride as the reducing agent. The study showed that treated water concentration of less than 10 ng/L of total mercury could be achieved (Looney, et al., 2003).

While these and other innovative technologies may offer some promise for the future of mercury treatment, none have been adequately demonstrated at either the pilot scale or a full scale application. Neither of the above innovative technologies has been demonstrated to be effective to the point where Site-specific pilot testing should be considered. The purpose of Site-specific pilot testing is to determine whether an already proven technology can be applied to the specific conditions of the water at a particular Site. For this Site, the unique characteristics of the leachate that would need to be evaluated in pilot testing could include elevated pH, the presence of dissolved organic matter, or salinity. However, until a technology has been demonstrated to be effective and the mechanisms for removal are understood, it is not possible to evaluate the effect of these variables on potential treatment effectiveness.

On-site Mercury Removal Research and Testing

Leachate from the Site is currently collected, treated on-site to reduce pH, and removed for disposal via deep well injection or at a local POTW. Other leachate management alternatives have been evaluated for the Site including treatment technologies that could potentially allow for direct discharge to surface water or discharge to a municipal wastewater treatment facility for final treatment prior to discharge.

As noted previously, mercury is typically not the primary dissolved constituent in water and other technologies would generally need to be employed prior to even attempting mercury treatment. This is consistent with collected CKD leachate characteristics at the Site. Existing water treatment operations begin with neutralization to reduce the pH, together with precipitation and clarification to remove the solids that form during the neutralization process, primarily calcium carbonate and calcium sulfate (gypsum). Any additional attempted mercury removal from Site leachate would occur after these processes have been completed and would need to incorporate additional treatment technologies.

Pilot testing was conducted at the Site to evaluate additional treatment steps. The treatment process studied included pH adjustment, enhanced chemical precipitation using a metal precipitating reagent (Nalmet) and coagulation using alum, followed by filtration using a membrane with a nominal pore size of 0.1 μm. The average influent mercury concentration during pilot testing was 500 ng/L. Results from the pilot testing showed that this combination of physical/chemical treatment processes had the potential to lower the mercury concentration in the treated water to an effluent concentration between 20 and 30 ng/L. This represents a significant decrease of total mercury of approximately 94 to 96 percent. However, the effluent values are still an order of magnitude above the water quality standard of 1.3 ng/L. This mercury remaining in solution is increasingly difficult if not completely infeasible to remove.

The pilot testing identified membrane fouling as a potential operational issue. The susceptibility of this technology to fouling was also recognized by the U. S. EPA in their review of treatment technologies (U. S. EPA, 2007). Management of mercury-containing residuals from the membrane treatment process and their final disposition is another important component of the overall technical and economic feasibility of this process. The preliminary results from this pilot testing were presented to the U.S. EPA and the Michigan DEQ at a meeting with CMS on January 18, 2006, and additional discussion of the work is included in Appendix D of the ECKD Area AE. The results of the Site-specific pilot testing for mercury removal are consistent with other published literature concerning mercury removal from water, as described in further detail below.

Additional Literature Review of Treatment Technologies

A recent review of the scientific and technical literature confirmed the results of the U. S. EPA's 2007 review, specifically that very few commercial technologies may be able to remove mercury from water to very low concentrations. Only one report of a technology able to achieve a treated water concentration of 1.3 ng/L was identified in the additional literature review and this has only been evaluated at pilot scale. That technology was a membrane bioreactor (MBR) used for the treatment of a municipal wastewater discharging into Lake Michigan (Holden, et al, 2005). MBRs employ biological treatment with activated sludge and membrane filtration for treatment, and this application also used alum to enhance precipitation and coagulation of particulates. The results of the pilot testing showed that the effluent concentration appeared to be quite sensitive to operating conditions (coagulant, sludge age, pH), but was reported to reduce the total mercury concentration from 13 ng/L to 1.3 ng/L. Although this technology may have the potential to achieve water treatment goals for mercury, it has not been effectively demonstrated in a full-scale application and the mechanism for mercury removal has not been elucidated in a manner that would allow this technology to be transferred to more complex wastewater, such as the leachate at the Site.

The development of materials for mercury adsorption is another area of on-going research. A number of new materials are being developed and tested at laboratory scale, but have not yet been shown to reduce mercury to the GLI requirements. Examples of materials under investigation include:

- Chitosan-derived adsorbents (Miretzky, 2009)
- Titanosilicates (Lopes, 2007)

- Synthetic chelating ligands (Blue, 2008)

Adsorption of mercury by a variety of adsorbents was also evaluated for a variety of sorbents at the Department of Energy's Oak Ridge National Security Facility in Tennessee (TN & Associates, 1998). None of the sorbents were able to remove mercury to below 12 ng/L. Interestingly, in a follow-up pre-design study, a system of three activated carbon treatment units in series was recommended for the full-scale operation and not one of the sorbents pilot-tested. Activated carbon was selected over other adsorbents because it was a demonstrated, full-scale commercial application; however, it only had the potential to reduce the concentration of mercury in the effluent to less than 51 ng/L (Tetra Tech, 2002).

Similar to the other innovative technologies identified by the U.S. EPA, none of these technologies has been adequately commercialized to consider Site-specific pilot testing.

2.5 Completed Removal Actions

Although it is impracticable to remove or contain all CKD or collect or contain all CKD leachate at the Site, there are practicable measures that can be implemented at the Site that can significantly reduce mercury flux to the lake. A significant amount of construction has been performed at the Site to address high pH impacts to the lake and these remedial elements have provided significant benefit to mercury reduction as well. The completed IR activities include a combination of technologies focused on addressing the exposure to waste materials, controlling the source, and aqueous plume remediation consistent with the ARS. Specific components associated with each of these objectives are summarized in Table 2-2.

The following sections summarize the IR removal actions and augmentations, operation and effectiveness monitoring programs, operation and maintenance activities, and effectiveness monitoring trends that clearly demonstrate the positive effect of existing removal actions in improving surface water quality and controlling mercury. The existing remedial elements will be incorporated into the ARS to the extent practicable, and together with additional proposed final remedial actions, will enhance exposure prevention to CKD and leachate, reduce leachate generation, and provide effective migration control of leachate to the lake.

2.5.1 Interim Response Removal Actions

IR removal actions consist of initial actions and subsequent augmentations to the initial actions. Initial IR actions were generally implemented to meet AOC requirements to address leachate discharging to Lake Michigan causing surface water pH exceedances. These actions were also implemented to aid in reducing the loading of other COCs, including mercury, to the lake. IR action augmentations were implemented to improve removal action reliability and/or improve the effectiveness of initial actions.

2.5.1.1 Initial Interim Response Removal Actions

At each CKD area, initial IR actions include installation of an interim leachate recovery system (ILRS). At the East CKD Area, initial IR actions to be incorporated into the final remedy, also included targeted removal and on-site consolidation of CKD and installation of an impermeable cover system.

An ILRS was designed and constructed, and is in operation at the Site as required by the AOC. The intent of the ILRS is to mitigate migration of leachate to the lake by means of interception through collection of leachate. Collection drains have been installed at the West, Seep 2 (including the Pine Court and Guard Rail Seep subareas), Seep 1, and East CKD Areas as shown in Figures 3-3 and 3-1, respectively. In general, the ILRS consists of segmented collection drains constructed in bedrock and unconsolidated material to various depths and lengths along the shoreline.

In addition to beach collection drains, the ILRS includes a leachate collection 'Edge Drain' that runs approximately 1200 feet along Coastal Ridge Drive in the northeast portion of the Seep 2 CKD pile (Figure 3-1). The Edge Drain collects perched leachate flowing over the edge of low permeability marker shale and has been in operation since 1997.

Lift stations were constructed to convey collected leachate through forcemain piping to Site treatment plants. Leachate is treated on-site at the treatment plants and is presently disposed of off-site using off-site deep well injection and a local POTW. ILRS record drawings are provided in Appendix 2-3 of the Development RI Report and Appendix X of the East CKD Area RI Report.

CKD from the east end of the East CKD Area, the 'bottleneck' area, was removed and consolidated in the western and central portions of the East CKD Area as shown on Figure 3-1. This targeted removal was performed because the CKD in this area was significantly impacting groundwater quality. Monitoring well W4119, which was located on the eastern portion of the area, had observed mercury concentrations as high as 129 ng/L prior to removal. The 'bottleneck' area CKD was confined to a small footprint and was located above lake elevation and it was anticipated to have a manageable volume of saturated CKD. These factors led to the conclusion that the 'bottleneck' CKD could be consolidated on-site. The CKD was consolidated and contoured to improve areas with poor drainage; specifically the southwest portion of the East CKD Area as shown on Figure 3-1. CKD materials were excavated to the east and south until field screening of surrounding soils indicated that the majority of the CKD had been removed. The excavation was pumped dry to facilitate the removal of CKD. However, due to the unevenness of the bedrock surface and the exposed fractures, it was infeasible to remove 100 % of the CKD and residual CKD remained. Nearly 36,000 CY of CKD was removed from the ‘bottleneck’ area. The removal was completed in early September 2006 and nearshore surface water quality initially spiked to above pH 11 in Lake Michigan, and did not consistently improve to below pH 9 for over three months. Clean imported soil was used to backfill the excavation. A low permeable clay barrier was constructed on the western limit of the excavation to provide a barrier between the excavation area and the CKD consolidation area. The groundwater sample collected from W4119r on April 15, 2009 yielded a mercury concentration of 1.7 ng/L, which is almost 99% lower than pre-IR (129 ng/L), but still above 1.3 ng/L.

Consolidated CKD in the western and central portions of the East CKD Area was graded and covered with an impermeable cover system generally consisting of six inches of sand bedding, 40 millimeter high density polyethylene (HDPE) liner, 12 inches of cover sand, 12 to 24 inches of rooting soil, and six inches of topsoil. The cover system also includes an extensive stormwater management system and asphalt parking areas and roadways. Additionally, an upgradient interceptor drain was installed in the Quarry Drive area to divert subsurface interflow.

Record drawings and detailed descriptions of the East CKD Area IR actions are provided in Appendix X of the East CKD Area RI Report.

2.5.1.2 Interim Response Removal Action Augmentations

Augmentation refers to activities conducted to improve initial IR action performance. Augmentation has been implemented at all CKD areas. Although the initial collection trenches are highly effective at intercepting leachate and mitigating elevated pH impacts in surface water, some discrete locations along the shorelines at each of the pile areas continued to have observable pH impacts. Significant augmentation activities at each CKD area are summarized in Table 2-3.

In addition to these augmentation activities, extensive cleaning of ILRS collection drains, lift stations, and forcemain piping is performed to assure collection system performance. An augmentation of the Pine Court ILRS is planned for fall 2009. The Pine Court ILRS will be modified to provide a dedicated forcemain from the Pine Court lift station to the treatment plant. This augmentation activity provides a method for long-term collection of leachate from the Pine Court seep subarea without having to mix lower pH Pine Court leachate with higher pH leachate from the

West and Seep 2 CKD Areas, which was a source of fouling in the collection system previously. As discussed in Appendix 2-6 of the Development RI, groundwater has a high ratio of divalent to monovalent cations, while leachate has a low ratio of divalent to monovalent cations. Mixing the two fluids leads to precipitation of mineral precipitates (calcite) and fatty acids in the collection drains and forcemains. Leachate collected from the Pine Court seep subarea is primarily groundwater and this cannot be mixed with leachate from the other seep areas. The precipitation and fouling experiences at the Pine Court seep subarea prove that overpumping (i.e., drawing in clean groundwater with the leachate) on the Site collection drains will result in uncontrollable fouling.

The augmentation activities listed in Table 2-3 for the West, Seep 2, and Seep 1 CKD Areas have been implemented in response to post-ILRS construction monitoring data. IR removal action augmentations for these areas are described in detail in Section 2.2.3 of the Development RI Report. The augmentation activities listed in Table 2-3 for the East CKD Areas were performed in conjunction with initial IR actions based field observations during construction. The East CKD slurry wall was built in response to discovery of unconsolidated soils at the west end of the CKD extent and was installed to enhance collection system performance. The upgradient interflow collection system along the south side of the East CKD Area was installed in response to field observations of interflow during utility installation. IR removal action augmentations for these areas are described in detail in Appendix X of the East CKD Area RI Report. ILRS cleaning activities at all CKD areas have been performed in response to continuous system operational observations as well as monitoring data collection and review.

Comprehensive operational and effectiveness monitoring, as described in Section 2.5.1.3 have resulted in prompt and successful implementation of IR removal action augmentation.

2.5.1.3 Monitoring Programs

The removal actions have been comprehensively monitored and evaluated to characterize CKD leachate migration control and overall system performance. This comprehensive approach has resulted in implementation of proactive and methodical maintenance programs and removal action augmentations that have improved system reliability and effectiveness.

Multiple programs have been established to monitor the performance of implemented removal actions. Monitoring generally falls into one of three categories; 1) mercury flux monitoring, 2) ILRS operational monitoring and 3) effectiveness monitoring. ILRS operational monitoring is performed to identify deficiencies that may reduce the reliability of the ILRS (e.g., precipitate formation on pumps). Effectiveness monitoring assesses how successful implemented removal actions are at controlling discharge of leachate to the lake through surface water quality sampling and lakeshore pH monitoring. Mercury flux monitoring quantifies the mass of mercury flowing from the Site. These programs have employed a variety of techniques that have been iteratively refined based on evolving Site understanding. The monitoring programs are comprehensive in both the spatial area over which they have been applied and in the frequency of data collection and analysis.

Mercury Flux Monitoring

A mercury flux evaluation program has been developed collaboratively between CMS and U.S. EPA. The mercury flux evaluation program uses Site data in an application of Darcy's Law of flow in porous media to estimate the flux of mercury through shoreline cross-sections created by a network of GSI monitoring well nests (East CKD Area AE, Appendix A and Development AE, Appendix A).

The monitoring well nest network at the East CKD Area is consistent with the work plan approved by the U.S. EPA, detailed in Section 2.0 of the Monitoring Well Installation, East CKD Area, Mercury Flux Evaluation (Barr, 2008). The monitoring well network at the Development Area has been implemented consistent with the requirements agreed upon for the monitoring well network at the East CKD Area. Additional monitoring wells were installed in 2009 at the Development. The monitoring wells included in the mercury flux evaluation program are shown on Figure 2-5 for the East CKD Area and Figures 2-6a and 2-6b for the Development Area.

The complete mercury flux evaluation program will ultimately consist of four rounds of flux estimates at both the Development and East CKD Areas. The four rounds are representative of four consecutive quarters to account for seasonal and temporal variations in Site data. Each round consists of sample collection and analysis from each monitoring well in the network and measurement of groundwater and Lake Michigan elevations to estimate the hydraulic gradient at each monitoring well during that round of sampling and analysis. To date, three rounds of sampling have been completed at the East CKD Area and two rounds have been completed at the Development. Aquifer testing has been performed at each well used in the mercury flux evaluation to estimate hydraulic conductivity values in the vicinity of the monitoring wells.

The mercury flux evaluation program is an effective and conservative tool for estimating existing mercury mass loading to the lake and the effectiveness of existing removal actions at mitigating mercury flux to the lake. The mercury flux estimate is a conservative estimate for several reasons. First, as depicted in Figure 2-13, a collection trench has a capture zone that extends downgradient of the collection trench alignment. Therefore, mercury concentrations that are observed in the downgradient monitoring well network may not be representative of the mercury concentrations that are actually discharged to the lake, as some groundwater may be drawn back into the collection trench. Second, the mercury flux estimate does not account for any potential attenuation between the monitoring well and the lake. Third, the gradient calculation in the flux estimate assumes a horizontal distance from the well location to the lake, when in reality; groundwater travels a further distance as it flows from depth to the surface water. Mercury flux monitoring estimates are also an effective tool for evaluating remedial actions to be included as part of the Site ARS. Remedial actions in the ARS will target locations where remaining mercury flux is greatest and warrants additional consideration.

Effectiveness Monitoring – Surface Water Quality Sampling

A second monitoring program implemented at the Site is the collection of analytical samples from surface water. The location of the surface water samples collected at East CKD Area is shown on Figure 2-14. The corresponding results are listed in Appendix Y of the East CKD Area RI.

Surface water samples were collected along the shoreline at East CKD Area prior to and after implementation of IR activities. Several samples collected in 2006 contained mercury concentrations greater than 1.3 ng/L. The location of these samples is highlighted on Figure 2-14. Samples collected from the same vicinity in 2007, after implementation of the leachate collection system, had concentrations of mercury below the laboratory method detection limit. A statistical evaluation of the surface water quality was performed and described in detail in the East CKD Area AE, Section 1.3.2.3.

Effectiveness Monitoring – pH Monitoring

The effectiveness of IR removal actions has also been evaluated through shoreline pH monitoring. Pre-IR conditions were documented as part of the Targeted Shoreline Survey in the spring of 2005. This survey helped identify areas in Lake Michigan affected by the discharge of leachate and provided nature and extent information for ILRS design. These zones, defined by pH measurements greater than 9.0, are shown on Figures 2-5 and 2-6a/2-6b. Targeted Shoreline Survey data are presented in Appendix 2-1 of the Development RI Report and Appendix L of the East CKD Area RI Report.

Lakeshore effectiveness monitoring conducted after implementation of the IR actions demonstrates that IR actions are effectively controlling leachate discharge to the lake as demonstrated by lakeshore pH measurements below 9.0. The most recent effectiveness monitoring data (June 2009) showed a few isolated exceedances at the West CKD Area and Pine Court seep subarea. The impacts at West CKD Area are suspected to be the result of recent augmentation construction activities and are anticipated to subside with continued leachate collection at this area. The impact at Pine Court, though low level, is indicative of an on-going discharge in this area and is the subject of consideration for additional remedial components. The most recent effectiveness monitoring data at each CKD Area is shown in and Appendix 2-8 and Appendix Y of the Development and East CKD Area RIs, respectively.

The pH effectiveness monitoring program is an effective tool for characterizing the pre- and post-IR extent of leachate discharging to the lake. pH effectiveness monitoring is also an effective tool for evaluating remedial actions to be included as part of the Site ARS. Figure 2-8 shows an example of the pH monitoring data used to define the East CKD Area zone. Figure 2-15 shows current (2009) Effectiveness Monitoring pH results, indicating the effect of the IR actions.

Interim Response Monitoring

The ILRS contains a fully automated monitoring system that can be viewed remotely by operating staff. This system has been in place since inception of the ILRS and seasonal operating patterns are well documented. The automated system provides real-time leachate collection flow rates at the treatment plant and liquid levels in all lift stations. ILRS lift stations are equipped with level transducers that trigger warning and shut-off alarms if liquid levels exceed established set-points. Operating staff receive alarms remotely through a pager system. Redundancy for these alarms is provided with local float controls at each lift station. Forcemain cleaning has historically been triggered when operating staff observe abnormal flow rate decreases or when precipitate is physically observed on equipment. More recently, ILRS cleaning has shifted to a more routine cleaning schedule. The semi-routine cleaning schedules are a result of increased comprehension of seasonal precipitation trends in individual ILRS collection drains and forcemain segments.

In addition to the automated monitoring, operating staff perform routine walk downs of the ILRS and monitor collection trench elevation data through physical measurement of piezometer water elevations in various locations in each beach collection drain. Physical walk downs of the ILRS aide operating staff with identifying maintenance issues and physical trench elevation measurements provide confirmation that water levels are being maintained to plan and that changes in conditions are responded to proactively. ILRS lift station pumps are inspected and cleaned to maintain reliability. Each lift station includes two pumps for redundancy. Additionally, spare pumps are kept on Site in the event that a pump needs to be sent out for cleaning.

Collection from the ILRS is, for all practical purposes, continuous. During cleaning and maintenance vacuum trucks or portable pumps are used to collect leachate while the ILRS is temporarily out of service. These alternate means of collection ensure that the ILRS continues to provide migration control of leachate.

Back-up power is a part of the leachate collection systems. A backup generator is in-place at the East CKD Area and quick connects and portable generators are on standby for the Development Area to power the leachate collection systems in the event electrical service is temporarily lost at the Site.

Operation of the ILRS is well understood, multiple methods of monitoring the system are employed, and cleaning of the ILRS is performed regularly without disruption to collection. The rigorous nature of this ILRS operational and monitoring program allows operating staff to react promptly to maintenance issues which in turn increases the reliability of the system.

Contaminant Concentration Trends

Trends in contaminant concentrations can be performed for the monitoring activities discussed above. The monitoring activities associated with mercury sampling and analyses are the focus of this discussion and include surface water quality monitoring and mercury flux evaluation.

As discussed previously, surface water samples were collected at East CKD Area in the locations shown on Figure 2-14. Samples were collected prior to implementation of the IR actions and a series of surface water samples have been collected after construction and operation of the ILRS. Analyses of mercury concentrations, along with potassium, pH, aluminum, and vanadium, provide good indication of whether the IR actions are effectively mitigating receptor impairment as the result of leachate discharge.

A review of samples from the two representative areas shown on Figure 2-14 was performed. There were significant reductions in pH, as well as potassium, aluminum, and vanadium concentrations. Two samples, East CKD Area Sample 2 and EAST CKD SW001, had mercury concentrations greater than the GSI criterion in the initial sampling events. Samples collected in the vicinity of these samples after construction of the leachate collection system contained mercury concentrations less than the laboratory method detection limit of 0.5 ng/L. Overall, the surface water quality improved 90% or better for the leachate-associated parameters suggesting that the leachate collection system is in fact, providing a substantial improvement to surface water quality. A detailed discussion with regard to the surface water quality evaluation is provided in Section 1.3.2.3 of the East CKD Area AE. The East CKD Area data provides a good demonstration of the capabilities of the removal action systems to drastically reduce leachate discharge at the Site.

The mercury flux evaluation provides a very useful, conservative, tool for examining the mercury loading to Lake Michigan over time as the full effect of the removal action activities are realized. The protocol for estimating mercury discharge to Lake Michigan is described in Section 2.5.1.3 and in detail in the Development AE. Use of the flux model provides a data-driven demonstration of mercury flux reduction as it relates to remedial action implementation. The mercury flux prior to implementation of IR measures at the East CKD Area was estimated to be 18.3 mg/day. Three rounds of mercury flux have been performed at the East CKD Area. The first, second, and third rounds yielded mercury flux estimates of 6.8, 14.3, and 1.2 mg/day, respectively for remaining mercury discharged to Lake Michigan. The data show an improving flux reduction toward the lake as the remedial components effect is realized. The last round provides better than 90% reduction in mercury flux, which closely resembles the reduction rates observed in the surface water quality evaluation, and provides another line of evidence demonstrating that the removal actions are highly effective at protecting Lake Michigan.

The estimates also served to highlight the effectiveness of specific removal action components taken. The pre-IR flux estimate at the ‘bottleneck’ was 1.7 mg/day. After removal of CKD, current estimates show that mercury flux has been reduced to 0.4 mg/day. This improvement demonstrates the effectiveness of the targeted removal, but also provides clear insight as to why complete removal is incapable of reliably achieving groundwater concentrations below the GSI criterion. The groundwater sample collected from W4119r on April 15, 2009 yielded a mercury concentration of 1.7 ng/L, which is almost 99% lower than pre-IR (129 ng/L), but still above 1.3 ng/L.

Site monitoring programs, including surface water sampling and mercury flux estimates, demonstrate that mercury loading to the lake is substantially lower following implementation of IR measures.

2.5.2 Predictive Timeframe Analysis

Evaluation of the West CKD Area beach excavation, as discussed in Section 2.3.4.1, provides insight as to the presence of CKD in bedrock factures multiple feet below the top of rock. The inability to effectively remove this material, and the residuals associated with performing the removal work subaqueous, lends to the persistent nature of CKD and its ability to emit mercury above the GSI criterion. The estimated timeframe during which mercury would remain above the GSI criterion is a minimum of 25 years and plausibly more than 50 years. Hindrances to mercury desorption could conceivably extend the timeframe to 100 years. This estimate was provided for 5% residual CKD (typical range of 4% to 7% and potentially higher in difficult removal conditions).

The lengthy restoration timeframe is indicative of the complex nature of the Site and the nature of the contaminant, mercury. The contaminant-related constraints are the significant mass of mercury present, the extremely low cleanup criteria, and the persistence of this metal. The primary geologic/hydrogeologic constraints are the variable permeability of the fractured bedrock, the extensive fracture network, the presence of CKD below the groundwater table, the complex groundwater flow patterns resulting from regional pumping, and the proximity to Lake Michigan. All other conceivable restoration activities, including the ARS, are anticipated to have timelines that are on the order of 100 years or more before groundwater is reliably restored (from the waste source) to below 1.3 ng/L. This neglects mercury in the groundwater from other sources, such as that observed in upgradient monitoring wells (up to 11.5 ng/L).

In contrast to the lengthy timeframe associated with restoration to below 1.3 ng/L, substantial mercury mass reduction can be realized almost immediately. The IR actions have been in-place for approximately four years and estimates of mercury mass loading have shown Site-wide reductions from approximately 107 mg/day to 53/day and is expected to fall to 24 mg/day with the completion of the remaining remedial components included in the ARS. It is expected that remedial action performance will improve with time as the full effects of the multiple remedial elements are realized.

3.0 Alternative Remedial Strategy

The U.S. EPA has established specific guidance for evaluating the technical impracticability of attaining groundwater clean-up criteria and establishing alternative, protective remedial strategies where restoration to a criterion is not practicable, the ARS. Impracticability of achieving the criterion may be demonstrated through factors such as hydrogeologic, contaminant-related, remedial technology limitations, or others. This impracticability has been demonstrated in the preceding sections of this Demonstration.

The purpose of the Demonstration was to demonstrate that it is technically impracticable to achieve the State of Michigan GSI criterion for mercury. This State criterion can be waived under CERCLA §121(d)(4) based on several factors including Technical Impracticability, or by the State through appeal to the Director and demonstration that the GSI standard is "Unachievable" pursuant to Michigan Environmental Remediation Standards Natural Resources and Environmental Protection Act (NREPA), §20104 of 1994 PA 451 Part 201 Rule 716 (17).

Since it is not practicable to achieve the State of Michigan GSI criterion for mercury, the ARS provides an approach addressing three items; (1) prevention of exposure to contaminated groundwater, (2) remediation of contamination sources, and (3) remediation of aqueous contaminant plumes to the extent practicable.

Developing an ARS that achieves remediation of the source and plume to the extent practicable requires a thorough understanding of the nature and extent of source material, leachate generation mechanisms and migration behavior, and the receptors. The extensive amount of investigative work and the observed effects of the IR systems have provided the foundation upon which a comprehensive SCM was developed, tested, and proven to appropriately represent the Site, thereby allowing for evaluation and selection of an ARS.

For the ARS, the primary elements of consideration include the following:

1. Mitigating plume discharge to the lake that will adversely impact surface water quality or provide exposure to leachate. The lake is the regional groundwater discharge zone and the plume beneath the CKD piles discharges near shore. The historical plume impacts in surface water are shown on Figures 2-5, 2-6a, and 2-6b.

2. Controlling the source of leachate resulting from saturated CKD. This is the predominant leachate generation mechanism due to its continuous nature. All four of the CKD pile areas contain saturated CKD. This results from perched or regional groundwater contact with the CKD piles. However, the East CKD Area is most significantly saturated by regional groundwater and the western portion of the Seep 2 CKD Area is most significantly saturated by perched groundwater.

3. Controlling the source of leachate resulting from precipitation by focusing on preferential infiltration areas rather than the entirety of the pile areas, where the scale of the pile areas can provide technical, logistical, and cost challenges. The piles span a footprint area of about 70 acres. For perspective, it would take more than 50 football fields to cover this area. However, despite the scale of the piles, the piles are covered and sloped to effectively drain in the majority of the areas. The exceptions are historically at the East CKD Area and currently in the western portion of the Seep 2 CKD Area where higher infiltration zones are more predominant (see Figures 2-5, 2-6a, and 2-6b). These areas allowed precipitation and melt water to contact CKD through the vadose zone and result in interflow along the top of the CKD surface and/or infiltrate through the waste.

4. Implementing measures that will effectively maintain the cover systems, mitigating the potential for CKD exposure, CKD erosion/migration, and leachate generation.

The formulation of the ARS reduces mercury mass loading (flux) to the lake by providing remedial technologies that address the four primary elements listed above.

- Collection of the leachate at the shoreline with an extensive system of collection trenches effectively mitigates the plume discharge to the lake by taking advantage of the natural groundwater flow pattern. At the Seep 2 CKD Area, the marker shale provides a confining layer where leachate pools, but eventually flows north over the edge of the shale and impacts deeper regional groundwater. To mitigate this and to minimize the subsequent downward migration of leachate in the regional aquifer via seasonal municipal pumping, collection of recoverable leachate is conducted with collection trenches and a TLC system.

- Upgradient groundwater diversion reduces the saturated CKD footprint and decreases leachate production to the extent practicable by minimizing the flow through CKD. These systems are focused on the areas of substantial saturated CKD resulting from regional groundwater (East CKD Area) and perched groundwater (western portion of the Seep 2 CKD Area).

- Targeted source removal provides reduction in saturated CKD footprint where practicable, and includes the eastern section of the East CKD Area ‘bottleneck’ and CKD mixed with soil at the beach of the West CKD Area.

- Targeted stormwater management system improvements at portions of the Seep 2 CKD and East CKD Areas minimizes the generation of leachate through preferential infiltration areas.

- Institutional controls and monitoring and maintenance programs assure that the cover systems over the CKD piles will continue to effectively mitigate exposure concerns and minimize leachate generation.

The details describing the ARS and the ability of the assembled remedial components to achieve significant mercury mass reduction are provided below.

3.1 ARS Components

As it has been demonstrated that achievement of Site-wide mercury concentrations less than 1.3 ng/L is technically impracticable, this ARS has been developed to address impacts at the Site. The ARS has been developed to achieve the following objectives: 1) exposure control, 2) source control, and 3) aqueous plume remediation. By achieving these objectives, the ARS reduces mercury concentrations to levels practicable and is protective of the human health and the environment. The following paragraphs describe the ARS at the Site and how these objectives are addressed by the ARS

3.1.1 East CKD Area ARS – AE Alternative Two

The East CKD Area ARS includes on-site CKD consolidation, compaction, and contouring; a cover system for the CKD; migration controls for groundwater; and institutional controls. The ARS addresses the objectives of exposure control, source control, and aqueous plume remediation through a selection of complementary remedial measures, as described in the following sections. The East CKD Area ARS plan is shown on Figure 3-1 and portions of the ARS are shown in a conceptual cross-section on Figure 3-2.

3.1.1.1 Exposure Control

The CKD pile has been consolidated, compacted, contoured, and covered to provide a significant physical barrier controlling direct exposure to CKD.

The IR leachate collection system intercepts discharge of leachate to Lake Michigan. This remedy practically eliminates the potential for direct exposure to leachate along the shoreline and minimizes impacts to surface water. The collected leachate is treated with physical/chemical processes to neutralize pH and settle the flocculated solids, which removes metals and thus reduces toxicity, mobility, and volume (TMV). The disposal of the treated water is to a permitted disposal location.

Institutional controls provide community protection in the form of groundwater use restrictions and engineered cover maintenance. As discussed in Section 2.5.1.3, significant reductions in pH, as well as mercury, potassium, aluminum, and vanadium concentrations, have been realized. Overall, the surface water quality improved 90% or better for the leachate-associated parameters suggesting that the leachate collection system is in fact, providing a substantial improvement to surface water quality.

3.1.1.2 Source Control

The consolidation, compaction, contouring, and covering of the CKD pile at East CKD Area serve to minimize the migration of contaminants to groundwater, thereby reducing the mass flux of COCs from source material to groundwater and subsequently to surface water. Contouring efforts eliminated preferential surface drainage and infiltration areas, reducing the volume of water that contacts the source, and thus reducing the generation of leachate. The entire remaining CKD pile at East CKD Area is covered by a geomembrane cap system, limiting infiltration of precipitation and run-on into the CKD pile.

Upgradient diversion is proposed as part of the recommended alternative at the East CKD Area. A corridor of diversion wells has been installed upgradient of the CKD pile to intercept regional groundwater as it flows towards the CKD pile. Diversion of upgradient groundwater decreases the volume of leachate generated to the extent practicable, reducing the potential of mercury mass loading to Lake Michigan. By reducing the volume of groundwater flow toward the pile, diversion in turn flattens the groundwater table over a wide range of conditions observed at the Site, reducing the hydraulic gradient generated by head differential between the regional groundwater table and Lake Michigan.

3.1.1.3 Aqueous Plume Remediation

Source control measures and collection activities serve as methods of plume remediation. The proximity of the CKD pile (source) to Lake Michigan (receptor) necessitates source control measures to limit the generation and migration of the plume. The IR collection systems collect leachate and a mixture of leachate and groundwater along approximately 900 feet of shoreline at the East CKD Area as shown in Figure 3-1 before it discharges to the lake. As discussed in Section 2.5.1.3, the mercury concentration data and mercury flux estimates have provided documentation that the implemented remedial measures have reduced the mercury concentration in the groundwater and controlled the migration of leachate to Lake Michigan.

3.1.2 Development Area ARS – AE Alternative Five

The Development ARS plan includes implementation of existing IR actions, including:

- Existing IR collection drains at the West CKD Area, Pine Court seep subarea, Seep 2 CKD Area (including Guard Rail Seep subarea and Edge Drain), and Seep 1 CKD Area,
- Downgradient barriers at the West CKD Area and Seep 1 CKD Area, and
- Maintenance of the existing CKD covers.

Additionally, the ARS components include targeted surface water improvements, upgradient groundwater diversion, and targeted leachate collection. The Development Area ARS plan is shown on Figure 3-3 and portions of the ARS are shown in a conceptual cross-section on Figure 3-4.

3.1.2.1 Exposure Control

The existing CKD cover system provides a direct exposure barrier to the CKD. Downgradient collection trenches intercept the discharge of leachate to Lake Michigan reducing the mass flux of COCs from impacted groundwater. This remedy nearly eliminates the potential for direct exposure to leachate along the shoreline and minimizes impacts to surface water. Institutional controls provide community protection in the form of groundwater use restrictions and cover maintenance. The CKD/soil on the beach of WCKD was removed, effectively mitigating the direct exposure risk previously posed by its presence.

3.1.2.2 Source Control

The existing CKD cover system reduces the migration of contaminants to groundwater, thereby reducing the mass flux of COCs from source material to groundwater and subsequently to surface water. The CKD/soil removal from the beach of WCKD mitigated the source of leachate generation downgradient of the collection drain.

Reduction of infiltration from surface water improvements limits the volume of leachate generated and is also expected to reduce the magnitude of peak flows historically observed at the Pine Court seep subarea ILRS improving downgradient hydraulic containment and reliability during wet weather conditions.

Perched groundwater diversion in the Seep 2 CKD Area will enhance downgradient hydraulic containment by reducing groundwater contact with CKD decreasing both groundwater flow and groundwater elevation above the marker shale.

Targeted leachate collection in the Pine Court seep subarea will enhance downgradient hydraulic containment by reducing leachate flow to the regional groundwater table and reducing groundwater contact with CKD above the marker shale in the vicinity of the recovery wells.

3.1.2.3 Aqueous Plume Remediation

As with the ARS at East CKD Area, source control measures serve to satisfy the objective of providing aqueous plume remediation. Downgradient leachate collection and TLC serve to remove impacted water prior to discharge to the receptor. The collection trenches span a total of approximately 3,000 feet of shoreline at West, Seep 2 (including the Pine Court and Guard Rail Seep subareas), Seep 1, and East CKD Areas as shown in Figure 3-1.

3.2 Mercury Flux Evaluation

As discussed previously, the mercury flux evaluation protocol provides a useful tool for examining mercury flux to Lake Michigan over time as the full effect of the ARS is realized. The protocol for estimating mercury flux to Lake Michigan is described in Section 2.5.1.3 and in detail in the Development AE. Use of the flux evaluation protocol provides a data-driven demonstration of mercury flux reduction as it relates to ARS implementation.

The mercury flux evaluation protocol is based on Darcy’s law for flow through porous media. A flux boundary is constructed along the shoreline with a network of groundwater monitoring wells defining discrete flux input parameters. The boundary includes well nests located between the collection trenches and Lake Michigan along approximately 3,900 feet of shoreline at the Development Area and East CKD Area as shown in Figures 3-1 and 3-3 respectively. Currently, three and one round of sampling and analysis have been completed at the East CKD Area and the Development, respectively. The mercury flux evaluation is planned for a full year to validate the known mercury extent and seasonal variations at the Site. While characterization of the fractured bedrock in a high energy environment is a challenge, the existing flux monitoring well network is a robust set of nested monitoring wells nearshore which provide a straight-forward deterministic methodology.

A summary of the mercury flux loadings evaluated to date are included in Table 3-1 and the overall mercury mass removal effectiveness of the ARS is shown illustratively in Figure 3-5.

3.2.1 Review of Existing IR Actions to reduce Mercury Flux

Existing IR actions are highly effective at controlling lakeshore pH below 9.0 with occasional excursions. The IR actions also effectively reduce mercury mass across the East CKD and Development Areas, with the exception of the Pine Court seep subarea. The mercury flux evaluation indicates that mercury flux is reduced by approximately 54 mg/day down from an initial mercury flux of 107 mg/day (see Table 3-1) with the IR actions. Nearly 43 mg/day of the remaining 53 mg/day is located in the Pine Court seep subarea. The Pine Court area is complex as discussed previously in the SCM in Section 2.3.6.2. The area has perched groundwater and interflow that saturates CKD above the marker shale generating leachate that pools on the shale and then flows over the edge into the regional groundwater. City Well 5 pumping subsequently draws the leachate deeper into the aquifer. Thus, the focus of the ARS is to build on the existing IR actions and enhance mercury flux reduction performance at the Pine Court seep subarea, to the extent practicable.

3.2.2 Proposed remedial components to further reduce Mercury Flux

Remedial actions proposed for the Pine Court seep subarea include surface water drainage improvements, perched groundwater diversion, and controlled regional groundwater diversion. In combination, these actions along with Pine Court ILRS operation will reduce peak mercury flux during spring months by an estimated 27 mg/day. It is also expected that implementation of upgradient regional groundwater diversion at the East CKD Area will benefit both mercury flux and reduce the volume of leachate that needs to be collected (by reducing the amount of leachate produced).

When implemented, the existing IR remedial actions combined with the proposed Pine Court seep subarea improvements and East CKD Area diversion system are expected to result in a remaining mercury flux to the lake of 24 mg/day (83 mg/day removed). This constitutes an approximate 78 percent reduction of the current mercury flux. A summary of the mercury flux toward the lake before IR actions, with the existing IR actions, and predicted with the full implementation of the ARS, are provided in Table 3-1. The full ARS may prove more effective over time than shown in the estimate, as the layering of multiple measures may have synergistic effects that are not captured in the calculations.

3.3 Cost

ARS cost estimates were prepared as part of the comprehensive evaluation of potential remedial alternatives. Total estimated costs include: 1) capital costs to design, construct, and implement remedial actions, and 2) operation and maintenance costs to operate, monitor, and evaluate remedial actions. Short-term (e.g., incurred during construction) and long-term leachate collection and disposal costs were included in operation and maintenance costs. The estimated ARS costs are shown in Table 3-2.

Detailed cost estimates for all remedial alternatives considered, including full removal and full on-site CKD containment, are provided in Appendix E for the Development Area AE and Appendix J for the East CKD Area AE. Detailed costs for full collection of the aqueous plume were not evaluated because full collection was deemed impracticable early in the remedial alternative screening process.

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Tables

Investigation Category	Investigation Activity	Site Conceptual Model Components				
		Geology and Hydrogeology	Contamination Source (CKD)	Leachate Generation/Release	Leachate Migration/Transport	Discharge/Receptors
Preliminary Investigations	***Review of Site Background (aerial photos, Sanborn Fire Insurance Maps, and Site development documentation reports)***		General understanding of CKD pile locations.			
	CKD Research		General understanding of CKD chemical and physical properties.	General understanding of leachate generation from CKD, general understanding of leachate characteristics.		
	Geologic Research	General understanding of regional geology. Regional geology consists of thinly bedded to thickly bedded limestone or shale bedrock overlain by weathered bedrock and/or unconsolidated glacial or lacustrine deposits.				
	Surface Hydrology Research	Surface water divide ~1/2 mile south of Site where surface water south of divide flows toward Walloon Lake, and surface water north of divide flows toward Lake Michigan; Identified three unnamed creeks on the Site that represent a surface expression of the water table elevations across the Site; Identified golf course subsurface drain system and irrigation system.		Identified the potential generation of leachate from golf course irrigation.		Identified three unnamed creeks at the Site that maybe potential receptors of leachate.
	Hydrogeologic Research	Lake Michigan is regional receptor of groundwater in the vicinity. Shallower regional groundwater discharges "near shore" in the Lake. Flow through bedrock occurs through fractures and along bedding planes.				Lake Michigan is regional receptor of groundwater.
	1995 Hydrogeologic Investigation	General understanding of non-CKD soils. Water levels measured in monitoring wells indicated that groundwater flows toward Lake Michigan.		Identified generation of leachate upgradient of the "Edge Drain."		
	2003 Geotechnical Investigation		Characterized the physical properties of CKD.	Identified surface water infiltration accumulating above the CKD surface.		
	U.S. EPA and MDEQ Lakeshore Monitoring and Sampling			General understanding of COCs in leachate generated from the Site.	Presence of high pH leachate at lakeshore documented.	Identified general areas of leachate discharge to Lake Michigan.
	Preliminary Lakeshore Evaluation (Fall of 2004)					Preliminary assessment of leachate discharged to lake (location and pH distribution), work used to develop procedures for targeted shoreline survey.
	Surface Geophysics	Approximate bedrock topography; potential locations of significant bedrock fractures; facilitated preliminary selection of boring/rock coring locations.	Preliminary extent of CKD/leachate plume.			

Investigation Category	Investigation Activity	Site Conceptual Model Components				
		Geology and Hydrogeology	**Contamination Source (CKD)**	**Leachate Generation/Release**	**Leachate Migration/Transport**	**Discharge/Receptors**
	Geologic Mapping	Strike and dip of bedrock units indicate that the bedrock is gently folded; dip and azimuth of bedrock fractures provided detailed assessment of bedrock fracture orientations; no karst features identified at the Site; measurement of bedrock fracture density at the surface.				
Summary of Preliminary Investigations		Developed understanding of regional geology and determined bedrock topography. Identified the presence of fractured limestone as prevalent bedrock feature underlying CKD waste piles. Regional groundwater discharge is to lake in vicinity and natural process is for shallow regional groundwater to discharge near shore. Developed general understanding of surface hydrology at the Site. Surface water infiltration and effectiveness of the subsurface drain system to be evaluated.	Identified the presence of four CKD piles and developed a general understanding of CKD chemical and physical properties. CKD contains both general parameters and metals as potential COCs. Surface geophysics provided a preliminary extent of CKD.	Identified sources of water to the CKD piles - groundwater and infiltration. Gained understanding that CKD can retard flow/infiltration due to its relatively low permeability. Developed general understanding of leachate chemical and physical properties and identified potential COCs in leachate generated from the Site.	Identified the presence of a completed pathway for leachate discharge to Lake.	Predominant leachate discharge zones identified downgradient of the CKD piles. Elevated pH readings observed along shoreline. Near shoreline impacts observed suggesting near shore discharge of leachate. Potential discharge of leachate to creeks to be evaluated.
Expedited Removal Actions	***Targeted Shoreline Survey***			Identified COCs in leachate generated from the Site.	Confirmed the presence of a completed pathway for leachate discharge to Lake.	Defined leachate discharge zones along Lake Michigan.
	Overflights					Confirmation of shoreline impacts defined by Targeted Shoreline Survey.
Summary of Expedited Removal Actions				Identified sulfate, arsenic, cadmium, chromium, iron, lead, mercury, nickel, potassium, sodium, and zinc as potential COCs in Site leachate discharged to Lake Michigan.	Confirmed the presence of a completed pathway for leachate discharge to Lake. Migration route from source of leachate generation to discharge point to be evaluated.	Predominant leachate discharge zones identified downgradient of the CKD piles. Highest pH readings observed along West CKD Area with pH ranging between 9.01 to 12.41, Pine Court Seep Area with pH ranging between 9.0 to 10.42, Guard Rail Seep Area with pH ranging between 9.02 to 9.71, Seep 2 CKD Area with pH ranging from 9.00 to 12.09, Seep 1 CKD Area with pH ranging from 9.00 to 12.45, and along the three discharge zones of East CKD Area with pH ranging between 9.00 to 12.40 for the central discharge zone, 9.25 to 11.23 for the eastern discharge zone, and 9.24 to 9.40 for the western discharge zone. Near shoreline impacts observed validating near shore discharge of leachate.

Investigation Category	Investigation Activity	Site Conceptual Model Components				
		Geology and Hydrogeology	**Contamination Source (CKD)**	**Leachate Generation/Release**	**Leachate Migration/Transport**	**Discharge/Receptors**
Response Action Investigations (Work Plan)	***Topographic Surveys***	Identified ground surface elevations of the Site.	Verified locations of four CKD piles.			
	Aerial Thermometry	Confirmation of nearshore discharge of groundwater to Lake Michigan.				
	Soil and Rock Borings	Site stratigraphy, verification and refinement of bedrock topography, no evidence of karst features, qualitative assessment of relative bedrock fracture density with depth, qualitative assessment of potential higher flow/hydraulic conductivity zones in bedrock, refined extent of marker shale.	Verification and refinement of CKD extent, identification of saturated CKD.	Moisture contents of CKD in boreholes provided evidence of leachate generation from infiltration, observations of saturated CKD provide evidence of leachate generation from groundwater contacting CKD.	Vertical pH profiles provided preliminary assessment of vertical extent of the leachate plume.	
	Dual-packer aquifer tests	Provided quantitative measurement of bedrock hydraulic conductivity distribution.				
	Slug Tests	Provided point measurements of hydraulic conductivities of unconsolidated materials and bedrock.				
	Vertical Pumping Tests (Monitoring Well Nest at B2042)	Confirmed the marker shale acts a barrier to vertical groundwater flow.			Marker shale will control vertical migration of leachate.	
	Creek Monitoring and Sampling					Provided evidence that leachate does not discharge to creeks.
	Stream gauging	Determined baseflow of creeks and identified gaining and losing reaches of creeks.				
	Metrological Investigation (Weather station)	Site weather data used with monitoring well data and collection drain data confirms groundwater flow response to rainfall/snowmelt events.		Continuous monitoring of weather conditions at the Site provided information of precipitation potentially correlating to leachate generation from infiltration.		
	Bay Harbor Lake Water Level Monitoring	Continuous monitoring of Lake Michigan/Little Traverse Bay elevation fluctuations; data allowed correlation between Site observations and lake elevations recorded at Mackinaw City gauge.				
	Monitoring Well Installation and Sampling	Observations during installation refined Site geology.		Sampling provides chemical properties of leachate, identifies location of leachate.	Sampling provides groundwater quality; leachate/potential COC distribution; identifies pathways of leachate migration, stiff diagrams generated from the monitoring well sampling provide evidence of leachate mixing with groundwater.	Results of analytical sampling from monitoring wells upgradient of the CKD piles and downgradient of the municipal wells provide evidence that leachate does not impact municipal wells.

Investigation Category	Investigation Activity	Site Conceptual Model Components				
		Geology and Hydrogeology	**Contamination Source (CKD)**	**Leachate Generation/Release**	**Leachate Migration/Transport**	**Discharge/Receptors**
	Long-term, Continuous Groundwater Level Monitoring and Discrete Groundwater Elevation Measurements	Confirmed hydraulic horizontal gradient toward Lake Michigan. Identified seasonal fluctuation in groundwater elevations that correlate to pumping of the City of Petoskey municipal wells. Seasonal changes in pumping of the municipal wells affects the groundwater elevations below the marker shale and in area where the marker shale is absent. Perched and seasonally perched groundwater identified in portions of the Site (typically above marker shale). Groundwater elevations in some wells show a flashy response to precipitation events while most wells have a non-flashy response.	Analyzing the regional groundwater elevations with the bottom of CKD surface identified areas of saturated and potentially saturated CKD.	Presence of saturated CKD supports the generation of leachate from groundwater contact. Flashy response to precipitation in wells provides evidence of greater leachate generation from infiltration during rainfall/snowmelt events.	For some portions of the Site, the influence of municipal wells on groundwater elevations indicate temporary downward and southern migration of leachate during periods of high municipal water use, which result in a more complicated migration path.	
	Unconsolidated Chemical Properties Analysis	Characterized the chemical properties of non-CKD unconsolidated soils.	Characterized the chemical properties of CKD.			
	Unconsolidated Physical Properties Analysis	Identified physical properties of non-CKD unconsolidated soils (grain size distribution, permeability, porosity).	Identified physical properties of CKD (grain size distribution, permeability, porosity).	Generally, permeability of CKD was less than the permeability of overlying non-CKD providing support for leachate generation from interflow along the CKD surface.		
	Leachate Characterization				Specific gravity analysis determined leachate mixes with groundwater and only has tendency to sink vertically for a short distance.	
	Downhole Geophysics	Quantitative assessment of relative bedrock fracture density and orientation. Distribution of bedrock layers with higher clay content (marker shale definition). Distribution of higher groundwater flow zones within boreholes. Temperature distribution within boreholes which may indicate connectivity with Lake Michigan or storm water infiltration.			Presence of dense fracture system within the bedrock identifies likely migration path of leachate through bedrock fractures. Location of marker shale which controls vertical leachate migration where shale is present. Locations of potential higher flow zones which may be indicative of greater leachate flows.	
	Ecological Investigation					Adverse impacts of CKD leachate discharge were not observed for organisms assessed.
	ECKD Area B4PW1 Pumping Test	Response of bedrock aquifer to pumping, results supported interpretation that the bedrock beneath the ECKD Area is an unconfined aquifer.				

Investigation Category	Investigation Activity	Site Conceptual Model Components				
		Geology and Hydrogeology	**Contamination Source (CKD)**	**Leachate Generation/Release**	**Leachate Migration/Transport**	**Discharge/Receptors**
Summary of Response Action Investigations (Work Plan)		Verified and further refined the bedrock topography interpreted from the surface geophysics. Confirmed the presence of fractured limestone as prevalent bedrock feature underlying CKD piles. Identified marker shale under portions of Site which acts as a vertical barrier to groundwater flow. Aquifer testing confirmed the bedrock is an unconfined aquifer and provided understanding of hydraulic parameters of subsurface. Determined groundwater flow is predominantly through a dense fracture system within the bedrock and is a equivalent porous medium. Validated understanding of the physical properties of the unconsolidated non-CKD soils. Determined groundwater in some portions of the Site (West CKD Area and Seep 2 CKD Area) is influenced by the pumping of the municipal wells which alters the groundwater flow paths. Identified perched groundwater in some portions of the Site (generally above the marker shale). Determined some portions of Site respond immediately to precipitation events indicating areas of increased infiltration or connectivity to surface hydrology.	Verified and further refined the extent of CKD interpreted from the surface geophysics. Identified areas of saturated CKD and estimated extents of CKD potentially saturated by groundwater. Characterized the chemical and physical properties of CKD.	Confirmed sources of leachate generation - infiltration and saturated CKD. Delineated leachate plume from results of monitoring well sampling. Moist/wet CKD located above the groundwater table provided evidence of leachate generation from infiltration, and saturated CKD below the groundwater table provided evidence of leachate generation from groundwater contacting CKD. The general permeability of CKD was determined to be less than the permeability of non-CKD indicating that leachate is likely generated from interflow along the CKD surface.	Confirmed overall migration of leachate toward Lake Michigan. Migration of leachate from the source to the Lake Michigan through bedrock is predominantly through the dense bedrock fracture system as indicated by elevated concentration of the COCs and pH observed in monitoring wells. Determined leachate sinks vertically into aquifer as a result of density and dispersive forces, but migration depth is limited due to counteracting forces of upward vertical gradient of groundwater and mixing with leachate. Pumping changes of the municipal wells influence in the migration of leachate in some portions of Site causing leachate to migrate downward and to the south. During normal conditions (low/no pumping of municipal wells) the migration of leachate is determined to be toward Lake Michigan.	Confirmed discharge of leachate to Lake Michigan. Determined three unnamed creeks were not receptors of leachate generated from the Site. Determined leachate does not discharge to the City of Petoskey Municipal Wells. Assessed organisms not impacted by CKD leachate.

Investigation Category	Investigation Activity	Site Conceptual Model Components				
		Geology and Hydrogeology	Contamination Source (CKD)	Leachate Generation/Release	Leachate Migration/Transport	Discharge/Receptors
Supplemental Investigations	***Geoprobe Borings (West CKD Area, Pine Court Area, and East CKD Area)***		Refined extent of CKD along West CKD Area beach, west portion of Pine Court Area, along horizontal extent of East CKD Area.			
	Additional Monitoring Well Nests (at B3017, B3042)	Define groundwater flow under West CKD pile and between West CKD Area and Seep 2 CKD Area. Defined geometry of shale between West CKD Area and Seep 2 CKD Area.		Characterize extent of leachate impacts west of West CKD pile.		
	Drainage System Survey	Verified locations of golf course drainage system infrastructure. Identified potential areas of high infiltration.		Identification of areas of potential leachate generation from infiltration.		
	Additional Rotasonic Borings (B2056-B2062) and TDEM geophysics at Pine Court	Refine extent of shale along south and west side of Pine Court Area, refine bedrock topography along east side of Pine Court Area, defines perched groundwater flow.	Refined CKD extent.		Evaluate leachate migration between CKD pile and Pine Court Seep.	
	Additional Rotasonic Borings (B2063-B2065)	Refine shale unit geometry on eastern portion of Seep 2 CKD Area.	Refine CKD extent.	pH profiling identified areas of leachate generation.		
	Additional Monitoring Well Nests (at B2063 and B2064)	Define groundwater flow along east portion of Seep 2 CKD Area.				
	Additional Shallow Bedrock Borings (B2066-B2069)	Refine bedrock type and topography near Edge Drain, defines location of perched groundwater.				
	Evaluation and Monitoring of Edge Drain				Determined where flow enters the Edge Drain and evaluate response to precipitation.	
	Geophysics Investigation along Seep 1 Beach	Refine top of competent rock, evaluate properties of soil and rock, provide near shore bathymetry data, refined location of preferential pathway of groundwater flow.				Refined location of preferential pathway of groundwater flow to receptor (Lake Michigan).
	Aquifer Testing of Seep 1 Beach Monitoring Wells	Defined hydrogeologic conditions near existing collection drains.				
	Assessment of CKD in Lake Michigan at East CKD Area		Identified four relatively small areas of cemented CKD located in Lake Michigan north of East CKD pile.	Determined disturbance of CKD in lake creates slightly elevated pH conditions in the surface water in the direct vicinity of the CKD.		
Summary of Supplemental Investigations		Refined bedrock topography in specific portions of the Site. Defined extent and geometry of marker shale present at Seep 2 CKD Area and West CKD Area. Confirmed presence of preferential flowpath through unconsolidated material at Seep 1 CKD Area. Defined extent of perched groundwater at Seep 2 CKD Area. Identified areas of potential high infiltration.	Refined extent of CKD along West CKD Area beach, west portion of Pine Court Area, east portion of Seep 2 CKD Area, and along horizontal extent of East CKD Area. Identified four areas of cemented CKD located in Lake Michigan north of East CKD pile.	Identified areas of potentially high infiltration confirming generation of leachate from surface water infiltration. Refined extent of leachate impacts along westside of West CKD Area and eastside of Seep 2 CKD Area.	Defined edge drain flow and response to precipitation. Determined migration of leachate from CKD pile to Pine Court Seep is complex due to the influence of varied pumping of municipal wells.	Refined location of preferential pathway of groundwater flow to Lake Michigan at Seep 1 CKD Area confirming zone of leachate discharge.

Investigation Category	Investigation Activity	Site Conceptual Model Components				
		Geology and Hydrogeology	Contamination Source (CKD)	Leachate Generation/Release	Leachate Migration/Transport	Discharge/Receptors
Village Harbor Investigation	***Geophysical Surveys***					Discharge of leachate from the East CKD Area is not responsible for pH>9.0 observed in the sump area of Village Harbor or in southwest corner of Village Harbor.
	pH/Specific Conductance /Temperature Profiling Survey			pH > 9.0 is limited to three areas in Village Harbor: immediately adjacent to the west side of the East CKD Area, the sump area, and the southwest corner.		
	Depth Profiling	Bottom topography of Village Harbor.				
	Sediment Sampling		Identified reactive material present in SW Corner and Sump Area.			
Bay Harbor Lake Assessment	***Shoreline Surveys and Underwater Dive Surveys***		Confirmed CKD is not present in Bay Harbor Lake.	Confirmed Leachate is not generated in Bay Harbor Lake.		Confirmed leachate does not discharge to Bay Harbor Lake.
Ice Study (MDEQ)	***Deep Water Monitoring***					No far offshore impacts observed; confirmed near shore venting.
Summary of Village Harbor, Bay Harbor Lake Assessment, and Ice Study Investigation		Determine Village Harbor bathymetry.	Verified CKD is not present in Bay Harbor Lake. Identified presences of reactive material (non CKD) in SW Corner and Sump Area of Village Harbor.	Confirmed leachate generation from East CKD pile impacts Village Harbor. Identified two other areas of elevated pH in Village Harbor (SW Corner and Sump Area). Confirmed leachate is not generated in Bay Harbor Lake.		Confirmed leachate generated from CKD piles discharges nearshore.

Interim Response Actions	***Installation of IR Collection Drains***	Installation of collection drains refined understanding of geology along shoreline.	Samples collected from West CKD Area collection drain trench refined understanding of beach CKD extent.			Confirmed discharge of leachate to Lake Michigan as IR drains were installed to intercept leachate discharging to lake.
	General Site Construction Activities Associated with IR Actions.	Identified perched groundwater upgradient of East CKD pile during installation of storm water management system and LCS forcemain south of CKD pile. Identified perched groundwater on west side of Seep 1 CKD Area during construction of access road. Monitoring of Seep 1 "Road Seep" confirmed perched groundwater flow responded to precipitation.		Identified leachate perched above regional groundwater at Seep 1 CKD Area "road seep."		
	East CKD Area Excavation	Refined bedrock surface.	Refined extent of CKD.	Refined sources of leachate generation.		
	WLCS Slurry Wall	Refined bedrock surface.				
	CKD Consolidation and Cover			Confirms understanding that leachate is generated from infiltration.		
	Operational Monitoring (Flow and pH leachate pH, collection trench elevations and pH, lake shore monitoring)			Confirms seasonal and precipitation responses of leachate generation.		Flow and pH monitoring confirms discharge of leachate to collection drains, operational lakeshore pH monitoring shows continued effectiveness of collection drains.
	Effectiveness Monitoring			Provided evidence that leachate generation was reduced with East CKD Area excavation and consolidation/cover.		Provides evidence that collection drains are effective at controlling the discharge of leachate to the Lake, identified non pH compliant areas which resulted in augmentation of interim response actions.

Investigation Category	Investigation Activity	Site Conceptual Model Components: Geology and Hydrogeology	Contamination Source (CKD)	Leachate Generation/Release	Leachate Migration/Transport	Discharge/Receptors
Summary of Interim Response Actions		Refined understanding of geology along IR drain alignments and east portion of East CKD Area. Identified zone of perched groundwater upgradient of East CKD pile and along Seep 1 CKD Area access road. Confirmed perched groundwater is influenced by precipitation.	Modified extent of CKD on eastside of East CKD Area. Refined extent of CKD on West CKD Area beach.	Confirmed understanding of leachate generation - infiltration and groundwater contact. Identified leachate generation from CKD saturated by perched groundwater along Seep 1 CKD Area access road. Removal of CKD from east portion of East CKD Area eliminated vast majority of leachate generation in area as evident in effectiveness monitoring results.		Confirms discharge of leachate to Lake Michigan. Determined IR drains are effective at controlling discharge of leachate to the lake. Identified non pH compliant areas along shoreline resulting in need for IR augmentation.
Interim Response Augmentation Design	***Seep 1 CKD Area Barrier Wall Design.***	Installation of piezometer nests and drilling of borings refined geology along Seep 1 CKD Area beach, rock testing characterized physical properties of bedrock, geotechnical samples characterized physical properties of unconsolidated material. Slug testing of piezometers used to determine hydraulic conductivity near Seep 1 CKD Area beach.				
	West CKD Area Downgradient Soil/CKD Removal Design	Installation of piezometer nests and additional borings refined bedrock surface along West CKD Area beach, geotechnical samples characterized physical properties of unconsolidated material at West CKD beach. Slug testing of piezometer nests determined hydraulic conductivity near WCKD beach.	Installation of piezometer nests, additional borings, and analytical sampling refined extent of CKD along West CKD Area beach.			Analytical samples confirmed the collection drains control leachate discharge to lake.
	Seep 2 CKD Area TLC System Design	Well installation refined geometry of marker shale and perched groundwater extent. Determined hydraulic conductivity of limestone in vicinity of B2025. Identified perched groundwater in the vicinity of the TLC wells responds rapidly to rainfall events.	Observations from TLC well installation refined extent of CKD and identified zone of saturated CKD in the vicinity of S2RW-2.	Well installation determined leachate generation from saturated CKD near S2RW-2, pH profiling and monitoring refined understanding of leachate generation from perched groundwater and infiltration.	pH profiling assessed pH distribution in perched groundwater. Pilot study evaluated flow of perched groundwater and migration of leachate. Identified that pumping from recovery wells can be effective at controlling migration of leachate to the west of the TLC system.	
	Pine Court CO_2 Pilot	Piezometer installation confirmed bedrock characteristics. Trench monitoring confirmed the seasonality of groundwater elevations, and Pine Courts IR drain responsiveness to precipitation.			Confirmed stratification and variable pH quality spatially and temporally.	Did not show significant influence on mercury removal.
Summary of Interim Response Augmentation Design		Refined geology and understanding of groundwater flow along eastern portion of Seep 1 CKD Area beach to aid in barrier wall design. Refined bedrock topography and understanding of groundwater flow along West CKD Area beach. Refine marker shale and perched groundwater extent near Seep 2 CKD Area TLC Wells.	Refined extent of CKD along West CKD Area beach. Identified CKD saturated by perched groundwater near S2RW-2.	Identified leachate generation from perched groundwater contacting CKD near S2RW-2. Refined understanding of leachate generation from infiltration and perched groundwater.	Determined effect TLC system has on leachate migration.	Confirmed IR drain at West CKD Area is effective at controlling migration of leachate to Lake Michigan.

Investigation Category	Investigation Activity	Site Conceptual Model Components				
		Geology and Hydrogeology	**Contamination Source (CKD)**	**Leachate Generation/Release**	**Leachate Migration/Transport**	**Discharge/Receptors**
Interim Response Augmentation	***West CKD Area Augmentation***	Excavation of soil/CKD along beach refined bedrock surface within excavation area, and confirmed presence of fractures in bedrock. Water conditions observed in lake during excavation and backfilling operations confirmed groundwater flow through bedrock fractures.	Modified extent of CKD along West CKD Area beach.			Water conditions observed in lake confirmed discharge of Site groundwater to lake. pH observed in excavation water confirmed collections drains effectively control discharge of leachate to lake.
	Seep 1 CKD Area Augmentation	Installation of barrier wall refined bedrock surface.				Increased collection of high pH leachate subsequent to barrier wall installation provides evidence that leachate migrated toward lake through preferential flowpath at Seep 1 CKD Area.
	Seep 2 CKD Area (TLC System, Temporary Pine Court Collection)	TLC confirmed presence of perched groundwater on shale.	Refined depth of CKD in TLC Area. CKD along bedrock escarpment identified. Confirmed CKD in contact with bedrock.	Saturated CKD releases leachate. Infiltration is indicated as a source of leachate at the toe of the slope. CKD saturated by perched groundwater is present throughout the year.	Water quality changes indicated in some area wells. Significant mercury removed with a steady source.	Established pH control during 2009 collection actions.
Summary of Interim Response Augmentation		Refined bedrock surface along east portion of West CKD Area beach and Seep 1 CKD Area Barrier Wall. Verified presence of dense interconnected bedrock fractures. Confirmed presence groundwater flow through bedrock fractures.	Modified extent of CKD along West CKD Area beach.	Saturated CKD releases leachate. Infiltration is indicated as a source of leachate at the toe of the slope. CKD saturated by perched groundwater is present throughout the year.	Water quality changes indicated in some area wells. Significant mercury removed with a steady source.	Confirmed discharge of groundwater containing COCs to Lake Michigan and discharge is controlled by IR drains. Confirmed presence of preferential flowpath for leachate migration toward Lake Michigan at Seep 1 CKD Area.
Flux Investigation	***Preliminary Flux Investigation***	Work Plan data indicated nearshore discharge in equivalent porous media.				Indicates a nearshore discharge.
	Installation of Mercury Flux Wells	Further refinement of geology along shoreline. New wells along western discharge zone confirmed quarry floor.				
	Sampling of Mercury Flux Wells			Indicates IR actions are controlling sources. Demonstrated seasonality of mercury flux.	Identified mercury concentrations migrating toward Lake which may or may not be captured. Confirmed migration control with IR drains.	
	Slug Testing of Mercury Flux Wells	Refined understanding of nearshore groundwater flow by determining hydraulic conductivities for each well.				Confirmed groundwater discharge to Lake and provided estimate of groundwater flow to lake
	Mini Pumping Tests of Mercury Flux Wells	Verified hydraulic conductivities from slug tests.				Provided lower groundwater flow to the lake than the slug tests.
Summary of Flux Investigation		Confirmed understanding of nearshore subsurface hydrogeologic conditions.		Indicates IR actions are controlling sources. Demonstrated seasonality of mercury flux.	Identified mercury concentrations migrating toward Lake which may or may not be captured. Confirmed migration control with IR drains.	Confirmed discharge of groundwater containing COCs to Lake Michigan and provided estimate of mercury flux discharged.

Investigation Category	Investigation Activity	Site Conceptual Model Components				
		Geology and Hydrogeology	**Contamination Source (CKD)**	**Leachate Generation/Release**	**Leachate Migration/Transport**	**Discharge/Receptors**
Final Remedy Design (East CKD Area Diversion System Design)	***Diversion well and observation well installation***	Well installation refined upgradient bedrock surface. Upgradient perched groundwater identified during well and conveyance piping installation.				
	Pumping Test and Groundwater Modeling	Additional characterization of hydraulic conductivity distribution in the bedrock beneath the East CKD Area. Refined understanding of groundwater elevations/hydraulic head. Observation from pumping tests determined perched groundwater has limited connection to regional groundwater.	Determined volume of saturated CKD is less than original estimate.	Determined volume of groundwater flowing through saturated CKD and generating leachate is less than original estimate.		Pumping tests and groundwater modeling quantified flow toward lake.
Summary of Final Remedy		Refined subsurface conditions upgradient of East CKD pile. Refined hydraulic conductivities of subsurface south of CKD pile. Refined hydraulic gradient across the East CKD Area. Determined perched groundwater has limited connection to regional groundwater.	Refined volume of saturated CKD.	Refined groundwater flow through saturated CKD resulting in less leachate generation. Identified potential source of leachate generation from upgradient perched groundwater contacting CKD as interflow.		Estimated groundwater flow and discharge of leachate.

Table 2-2
Interim Response Activities
Little Traverse Bay CKD Release Site
CMS Land Company

Category	**IR Actions**	**Specific Benefit**
Exposure Control	• Impermeable Cap at East CKD Area • Verified Soil Cover Integrity at Development • Targeted Removal of Soil/CKD at West CKD Area Beach	• No CKD is exposed at the Site. • Majority of pile cover systems are graded to drain minimizing infiltration.
Source Control	• Targeted Removal of Soil/CKD at West CKD Area Beach • Targeted Removal and Consolidation of CKD from East CKD Area bottleneck • Surface Water Improvements, Upgradient Interflow Interceptor, and Impermeable Cap at East CKD Area • Targeted Leachate Collection (TLC) at Pine Court	• Reduces CKD footprint/area available for leachate generation. • Minimizes leachate generation by addressing preferential infiltration zones. Impermeable cap nearly eliminates infiltration to CKD across East CKD Area. • Minimizes leachate generation by removing source (interflow) of water to pile. • TLC lowers water table across CKD footprint resulting in less saturated CKD and lower gradient, thus lower flow of leachate toward lake.
Aqueous Plume Remediation	• Shoreline Collection Drains • Edge of CKD Pile Drain • TLC at Pine Court • Vertical Barriers at West CKD Area, Seep 1, and East CKD Area	• Intercepts plume water prior to discharge in the lake. • TLC and Edge Drain remove leachate from the top of shale before it enters regional groundwater. • Vertical barriers aid in collection performance/minimizes capture of lake water.

Table 2-3
Interim Response Augmentation Activities
Little Traverse Bay CKD Release Site
CMS Land Company

CKD Area	IR Remedial Action Augmentation Activities
West	• expansion of the West CKD ILRS • removal of downgradient soil and CKD mixture • reconstruction of the West CKD ILRS • installation of a low permeability modified fill zone lakeward of ILRS • installation of a geosynthetic clay liner (GCL) cover system
Seep 2	• design, installation, operation, and modification of a pilot carbon dioxide injection system (later removed due to inconsistent effectiveness) • installation of a targeted leachate collection system (TLC) • installation of a temporary forcemain and leachate collection frac tanks
Seep 1	• installation of low permeability barrier wall • installation of a GCL cover system
East	• installation of a low permeability vertical slurry wall downgradient of the west leachate collection system • installation of an upgradient interflow collection drain

Table 2-4
Effectiveness of Water Treatment Technologies for Mercury Removal
Little Traverse Bay CKD Release Site
CMS Land Company

Technology	Test Scale	Lowest Reported Mercury Effluent
Precipitation/co-precipitation	Full	25 ng/L
Adsorption	Pilot/Full	<2,000 ng/L
Membrane Filtration	Full	<200 ng/L
Biological	Pilot	3,000 ng/L

Table 3-1
Mercury Flux Loadings
Little Traverse Bay CKD Release Site
CMS Land Company

Area	**Mercury Flux to Lake (mg/day)**		
	Pre-IR[1]	Existing-IR[2]	Full ARS[3]
West CKD	1.6	0.2	0.2
Pine Court Seep	45.3	42.6	17.8
Seep 2 CKD	27.8	0.9	0.9
Seep 1 CKD	14.3	1.9	1.9
East CKD	18.2	7.4	3.6
Site Total	**107**	**53**	**24**

[1] Pre-IR mercury fluxes were estimated using discrete mercury flux analysis when pre-IR beach well mercury analytical data was available. In the absence of pre-IR beach well mercury analytical data, an alternative method was used to estimate the pre-IR mercury flux as the sum of calculated post-IR mass flux and mass collected the in ILRS drains. This alternate method was used at the Development with the first round of discrete mercury flux. This alternate method was also used for the west leachate collection system area at the East CKD Area with the second round of the East CKD Area discrete mercury flux evaluation (first quarter of 2009). Appendix A in both the Development AE Report and the East CKD Area AE Report describe this methodology in greater detail.

[2] Existing-IR mercury fluxes were estimated using discrete mercury flux analysis with all available data as of winter 2009. The values shown for the Development Areas are based on the first round of Development Area discrete mercury flux estimation (first quarter of 2009). The value shown for the East CKD Area is the average of the mercury flux analysis for Rounds 1-3. Appendix A in both the Development AE Report and the East CKD Area AE Report describe this methodology in detail.

[3] Full ARS mercury fluxes were estimated using predictive mass reduction evaluations as detailed in the Development AE Report and the East CKD AE Report.

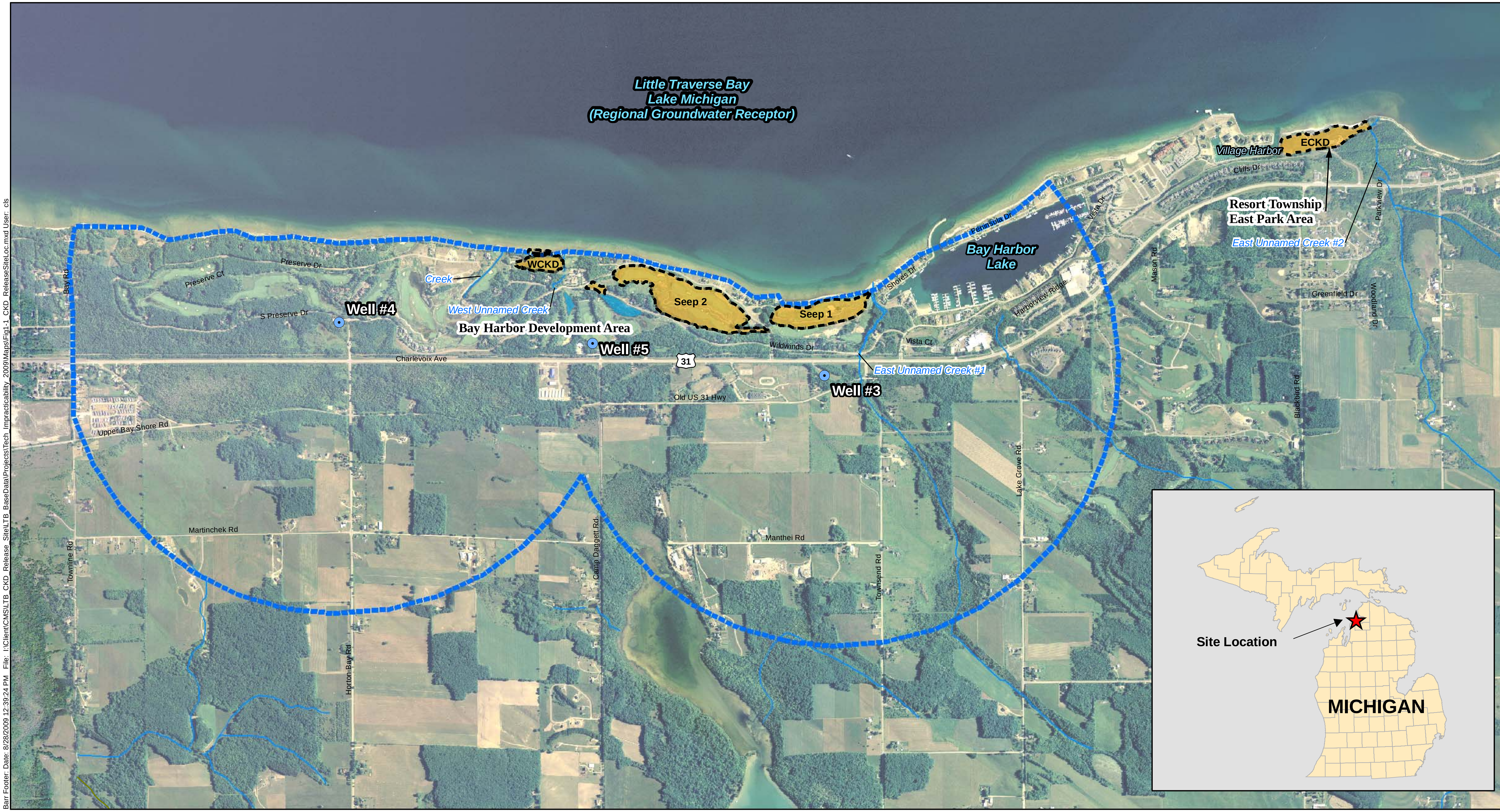
Table 3-2
Alternative Remedial Strategy Cost Estimate
Little Traverse Bay CKD Release Site
CMS Land Company

Area	Estimated ARS Cost (in millions)		
	Total Capital[1]	Total NPV O&M[2]	Total NPV Cost[2]
West CKD	$8.3	$7.9	$16.2
Pine Court Seep	$13.9	$17.7	$31.6
Seep 2 CKD	$9.0	$36.0	$45.0
Seep 1 CKD	$10.0	$19.4	$29.4
East CKD	$15.4	$11.0	$26.4
Site Total	**$56.6**	**$92.0**	**$148.6**

[1] Capital costs include costs to date.

[2] NPV is net present value assuming 30 years of operation and maintenance (O&M) with a 3 percent discount factor.

Figures



Imagery: 2005 USDA-FSA-APFO NAIP

- City of Petosky Municipal Well
- Creeks
- CKD Piles (Original)
- Well Head Protection Area
- Pond/Wetland

N

0 0.5 1 Miles

Figure 1-1

CKD RELEASE SITE LOCATION
Little Traverse Bay
CKD Release Site
Emmet County, Michigan

BARR

Imagery: 2005 USDA-FSA-APFO NAIP

- GSI Monitoring Flux Well Nest
- Creeks
- Approximate CKD Extent (Original)
- Technical Impracticability Zone

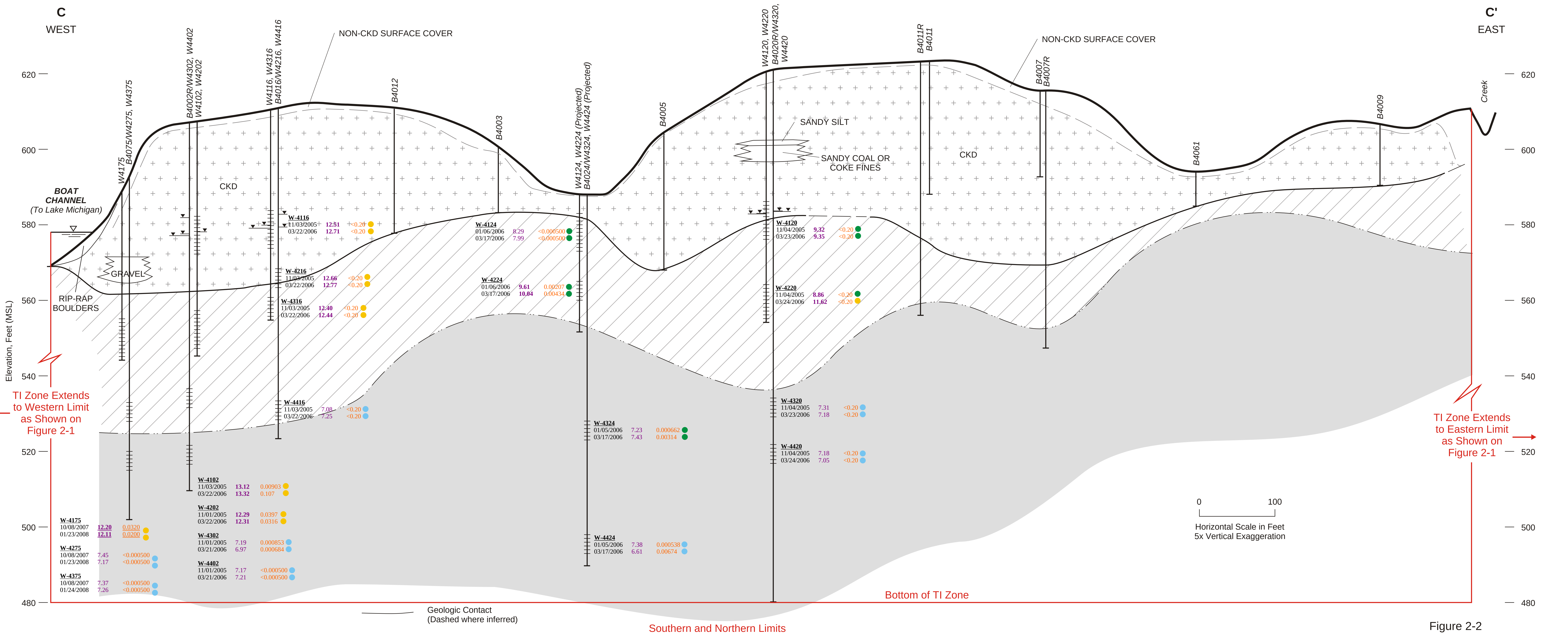
N

0 500 1,000 2,000 Feet

Figure 2-1

TECHNICAL IMPRACTICABILITY ZONE
Little Traverse Bay
CKD Release Site
Emmet County, Michigan

BARR



Geologic Contact (Dashed where inferred)

Ground Surface (Post 2006 Construction)

Weathered and/or Highly Fractured Limestone with Some Discontinuous Shaley and Silty Zones

NON-CKD SURFACE COVER
Generally topsoil consisting of variable amounts of sand, silt, and gravel. Plant organic matter is sometimes observed.

Approximate Top of Competent Rock (From seismic refraction models) Fractured Limestone with Some Discontinuous Shaley and Silty Zones

Cement Kiln Dust (CKD) Fill Material (Typically silt sized with some angular gravel or cobble clasts of limestone intermixed

Southern and Northern Limits of TI Zone as shown on Figure 2-1

Groundwater

Mixture of Leachate and Groundwater

Leachate

W-4124
Sampling Date 01/06/2006 8.29 <0.000500
Field pH Measurement
Mercury Result

Concentrations in ug/L.

* Estimated value, QA/QC criteria not met.

b Potential false positive value based on blank data validation procedure.

Bold - Exceeds MI 201 GW Res/Com DW Criteria

Underline - Exceeds MI 201 GSI Critreria

Figure 2-2

TECHNICAL IMPRACTICABILITY ZONE
East CKD Area
Little Traverse Bay
CKD Release Site
Emmet County, Michigan

BARR

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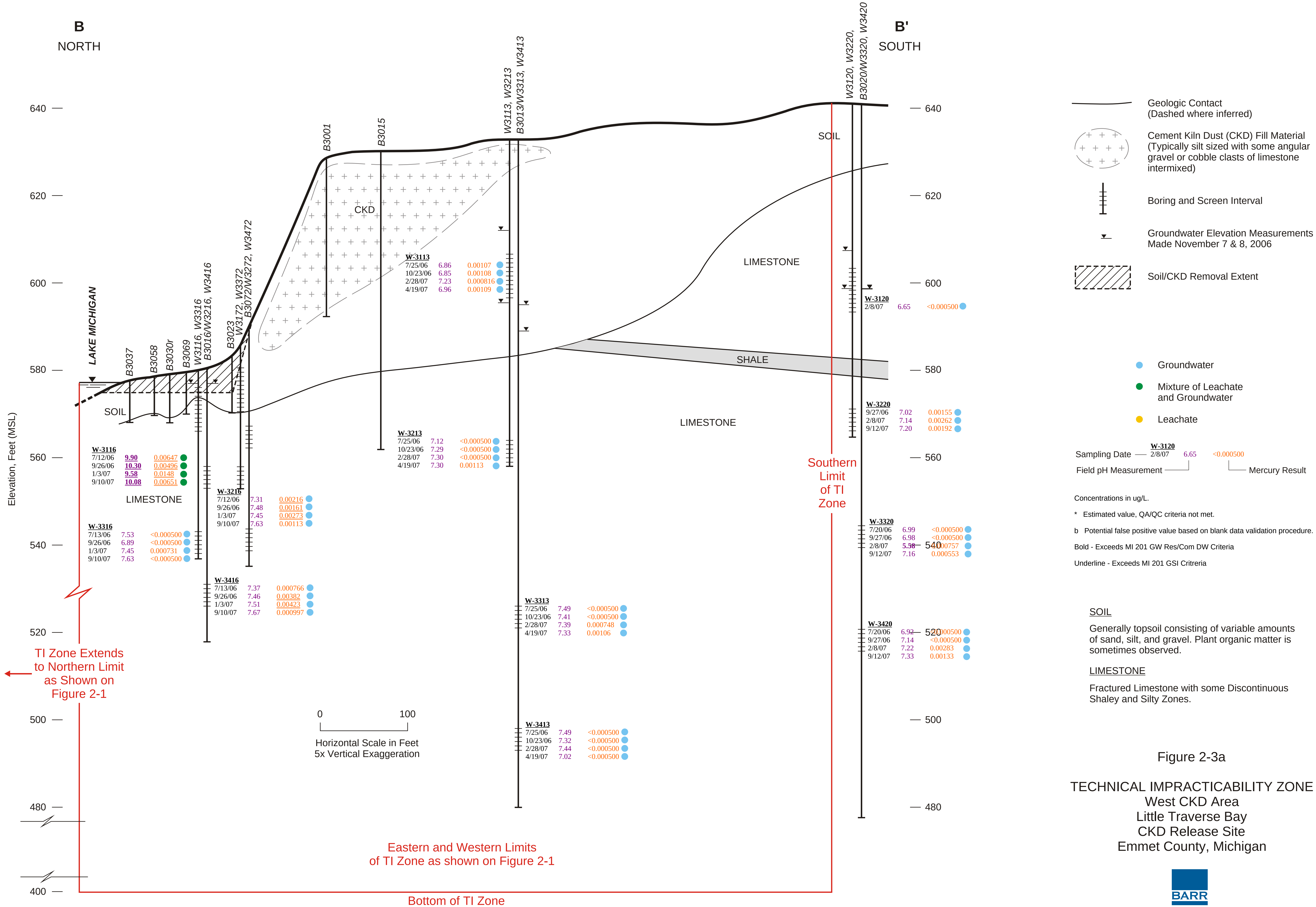

Figure 2-3a

TECHNICAL IMPRACTICABILITY ZONE
West CKD Area
Little Traverse Bay
CKD Release Site
Emmet County, Michigan

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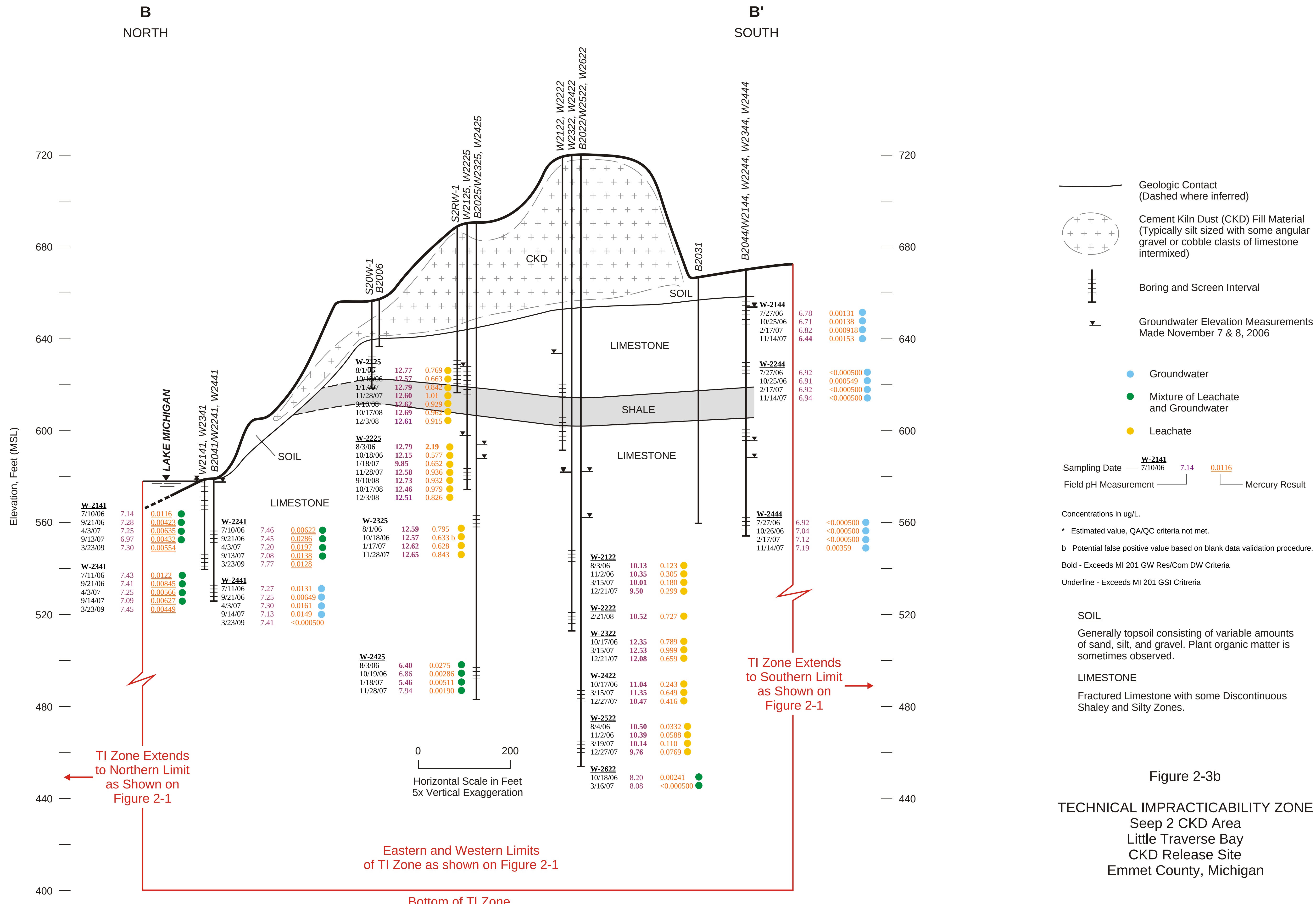

Figure 2-3b

TECHNICAL IMPRACTICABILITY ZONE
Seep 2 CKD Area
Little Traverse Bay
CKD Release Site
Emmet County, Michigan

BARR

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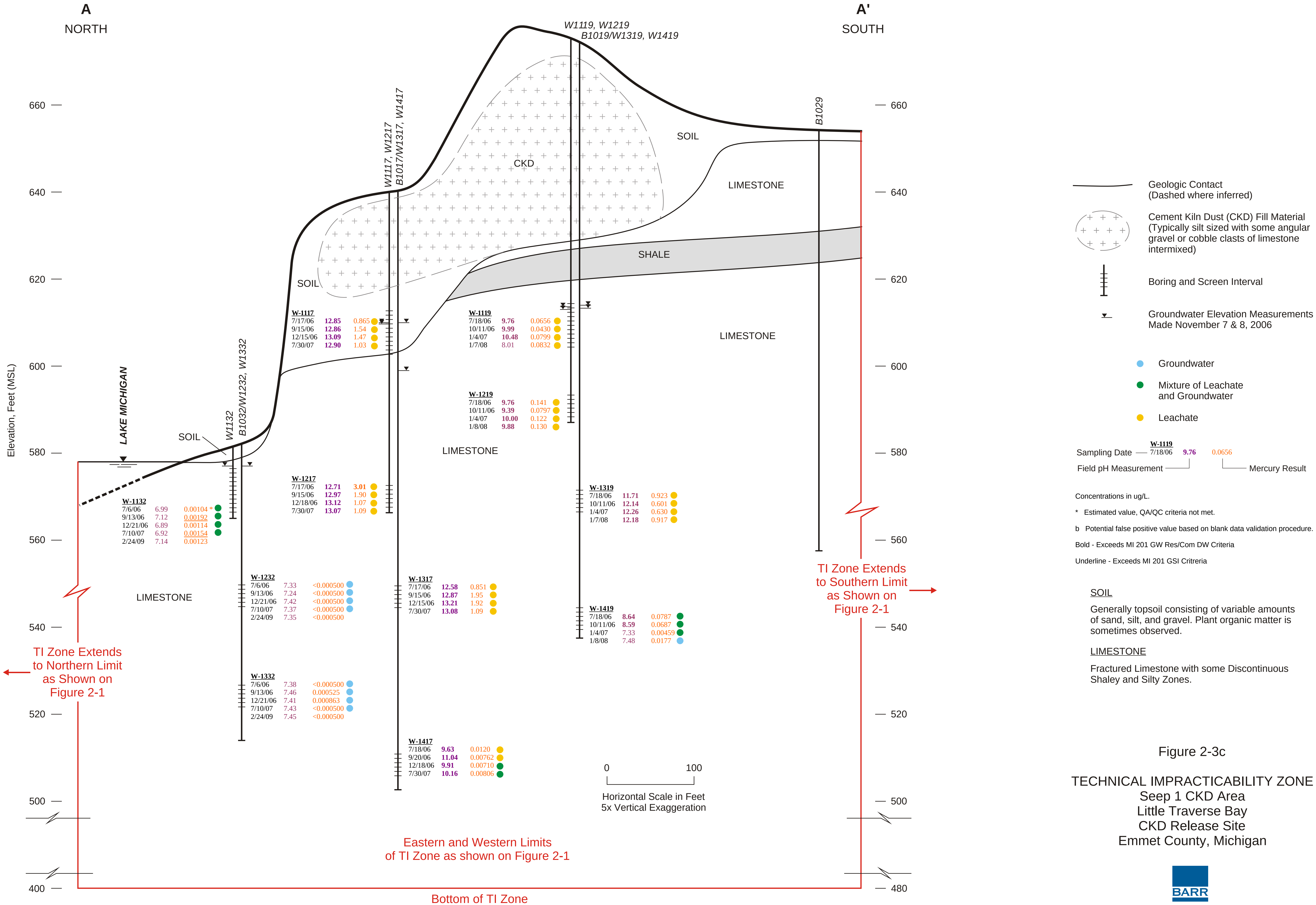

Figure 2-3c

TECHNICAL IMPRACTICABILITY ZONE
Seep 1 CKD Area
Little Traverse Bay
CKD Release Site
Emmet County, Michigan

BARR

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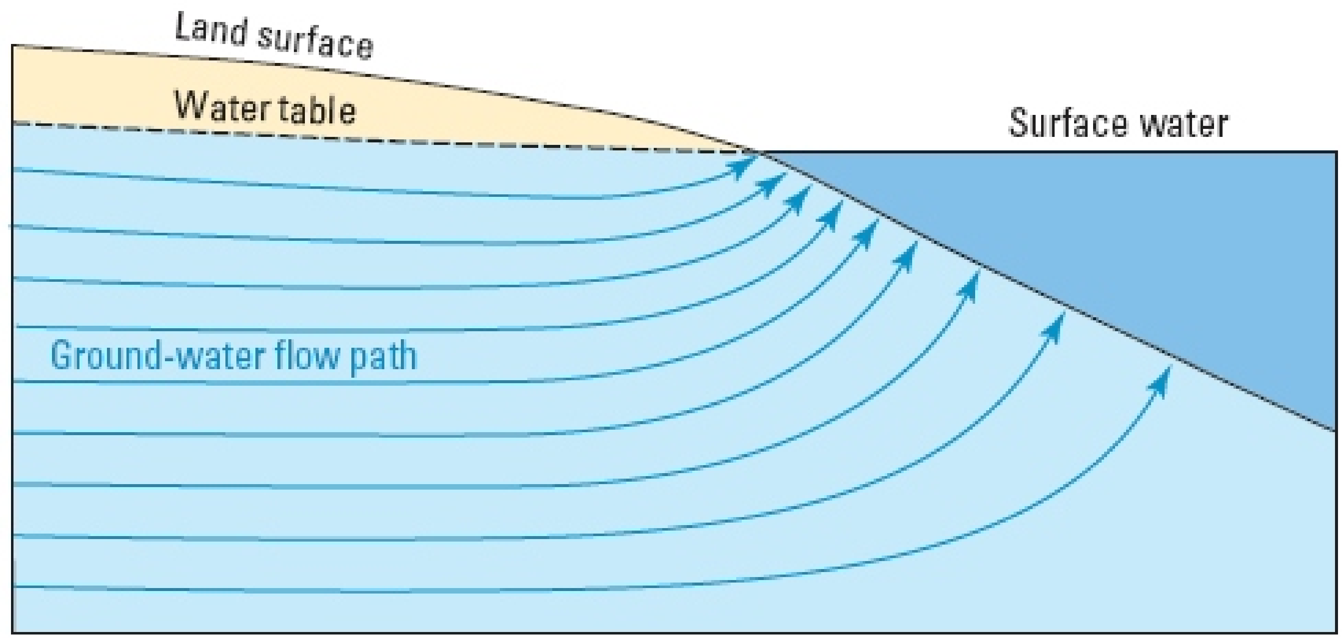
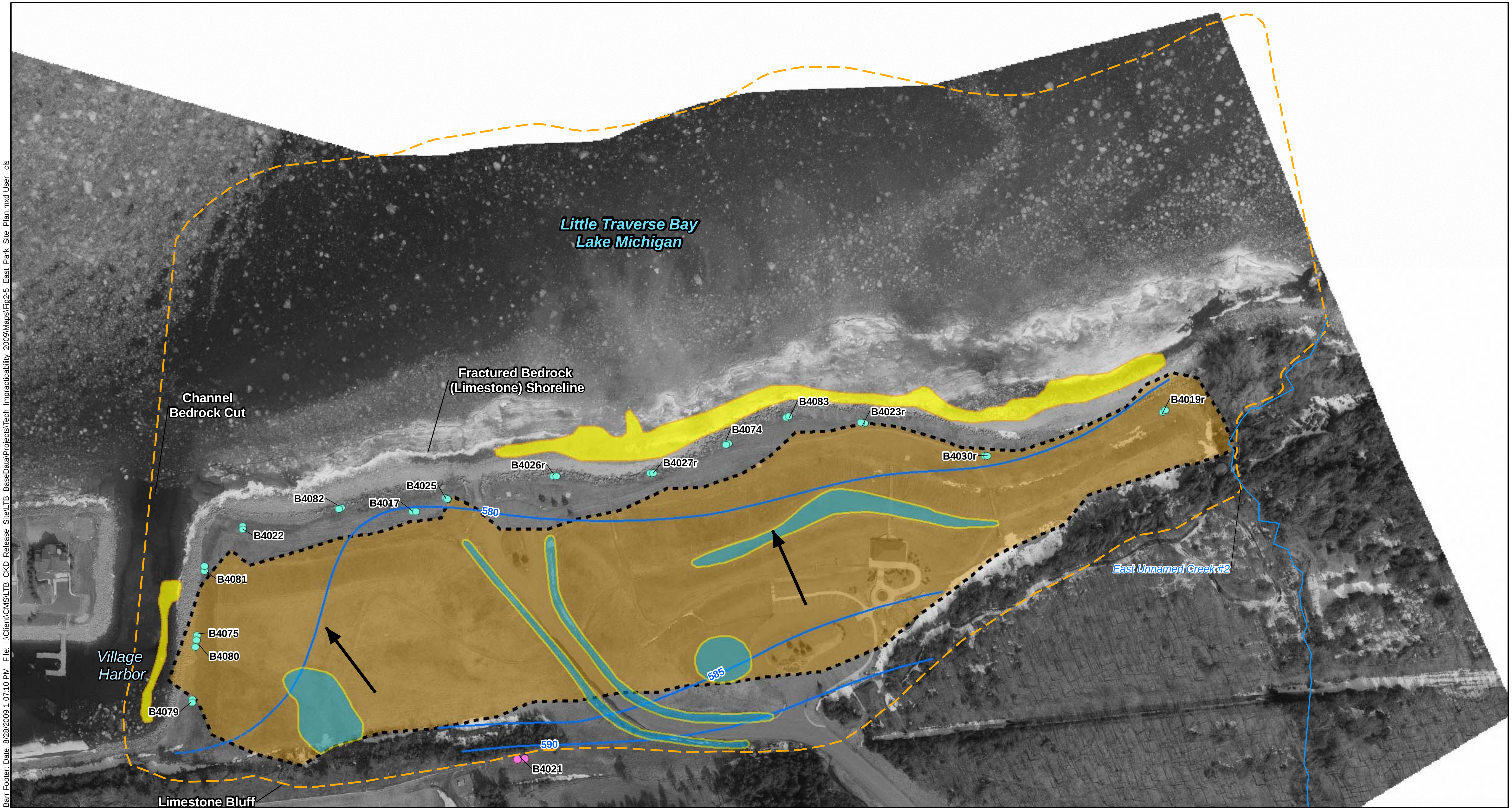


Source: Rosenberry, D.O., and LaBaugh, J.W., 2008. Figure 3, Decrease in seepage discharge with distance from shore (from Winter and others, 1998), from "Field techniques for estimating water fluxes between surface water and ground water," U.S. Geological Survey Techniques and Methods 4-D2, 128 p.

Figure 2-4

CONCEPTUAL NEAR SHORE GROUNDWATER FLOW
Little Traverse Bay
CKD Release Site
Emmet County, Michigan

BARR



Imagery: April 2005

- GSI Monitoring/Flux Well Nest (Existing)
- Upgradient Groundwater Monitoring Well Nest
- Generalized Groundwater Flow Direction

Groundwater Elevation (ft MSL) [July 2008]

- Contour Interval; 5 ft
- Contours Dashed Where Inferred
- Approximate CKD Extent (Original)
- Observed Leachate Discharge Zone
- Preferential Surface Water Infiltration Areas (Depressions, Ditches, Low/Flat Grades)
- Technical Impracticability Zone

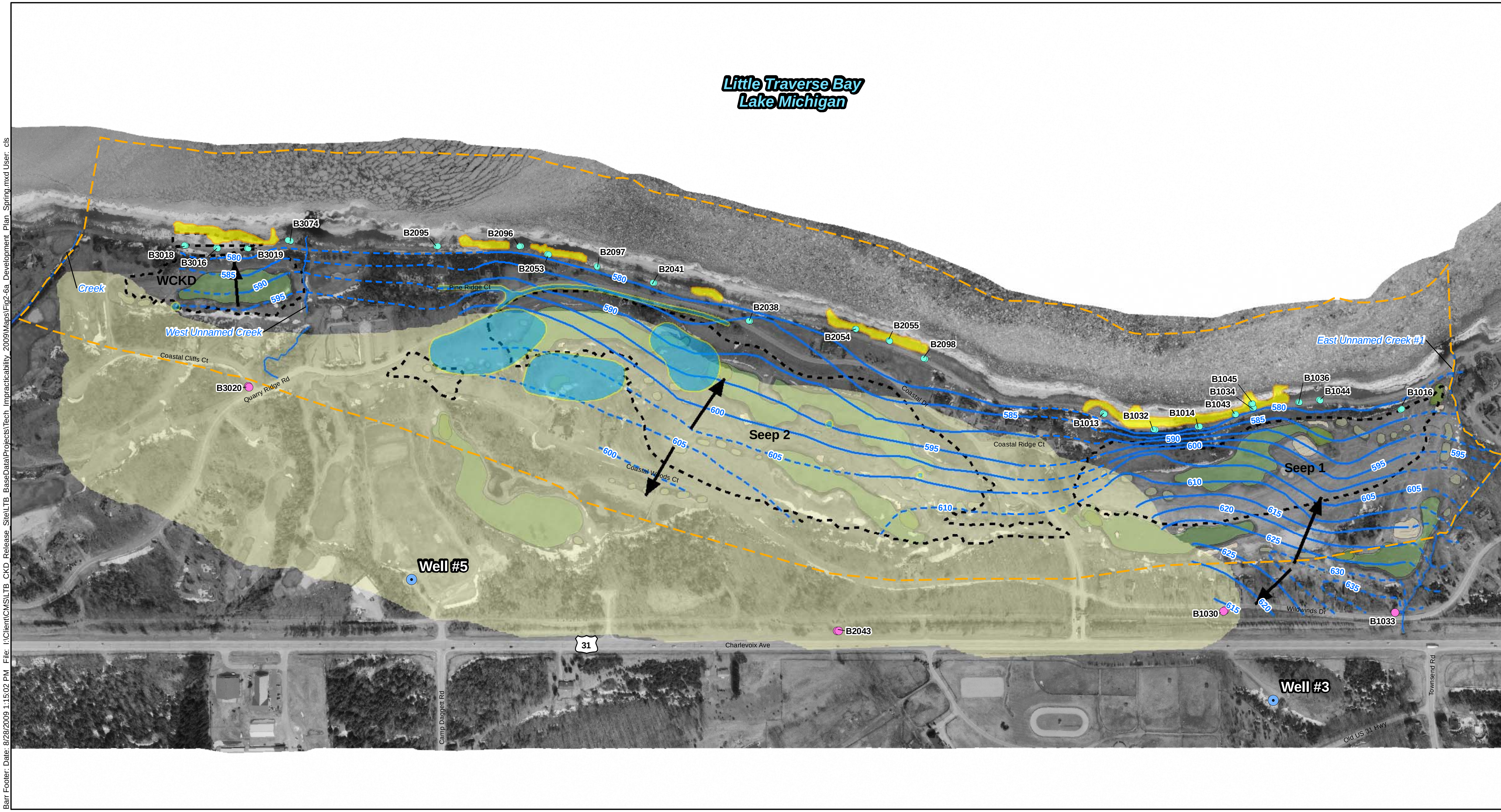
N

150 75 0 150 Feet

Figure 2-5

SITE PLAN
EAST CKD AREA
Little Traverse Bay
CKD Release Site
Emmet County, Michigan

BARR



Imagery: April 2005

- GSI Monitoring/Flux Well Nest (Existing)
- Upgradient Groundwater Monitoring Well Nest
- City of Petosky Municipal Well
- Generalized Groundwater Flow Direction

Groundwater Elevation (ft MSL) [MARCH 27-28, 2007]

- Contour Interval: 5 ft
- Contours Dashed Where Inferred
- Approximate CKD Extent (Original)
- Observed Leachate Discharge Zone
- Approximate Shale Extent
- Preferential Surface Water Infiltration Areas (Depressions, Ditches, Low/Flat Grades)
- Technical Impracticability Zone

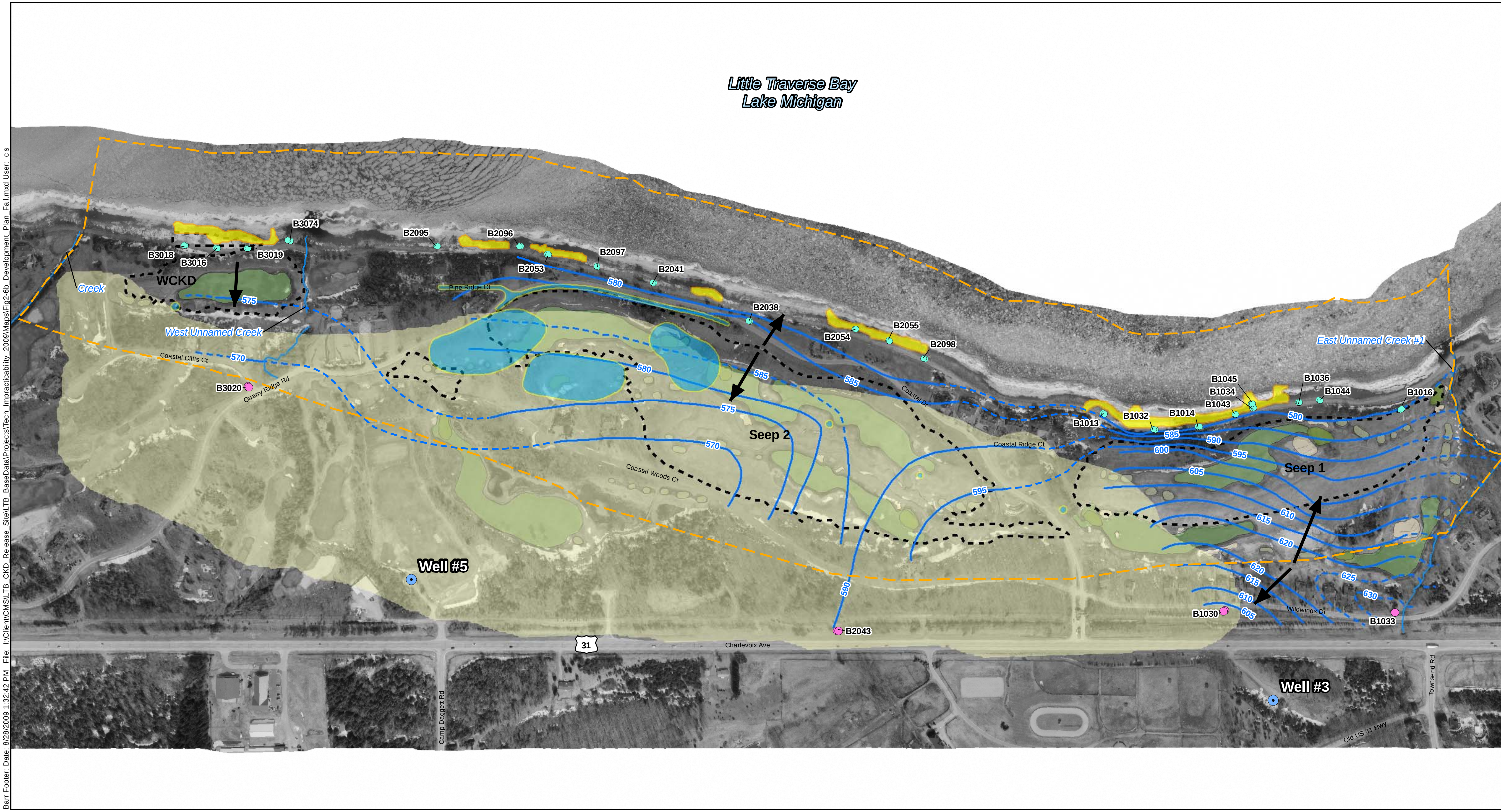
N

450 225 0 450 Feet

Figure 2-6a

SITE PLAN - SPRING DEVELOPMENT AREA
Little Traverse Bay
CKD Release Site
Emmet County, Michigan

BARR



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Imagery: April 2005

- GSI Monitoring/Flux Well Nest (Existing)
- Upgradient Groundwater Monitoring Well Nest
- City of Petosky Municipal Well
- Generalized Groundwater Flow Direction

Groundwater Elevation (ft MSL) [SEPTEMBER, 2006]

- Contour Interval: 5 ft
- Contours Dashed Where Inferred
- Approximate CKD Extent (Original)
- Observed Leachate Discharge Zone
- Approximate Shale Extent
- Preferential Surface Water Infiltration Areas (Depressions, Ditches, Low/Flat Grades)
- Technical Impracticability Zone

N

450 225 0 450 Feet

Figure 2-6b

DEVELOPMENT PLAN - FALL
DEVELOPMENT AREA
Little Traverse Bay
CKD Release Site
Emmet County, Michigan

BARR

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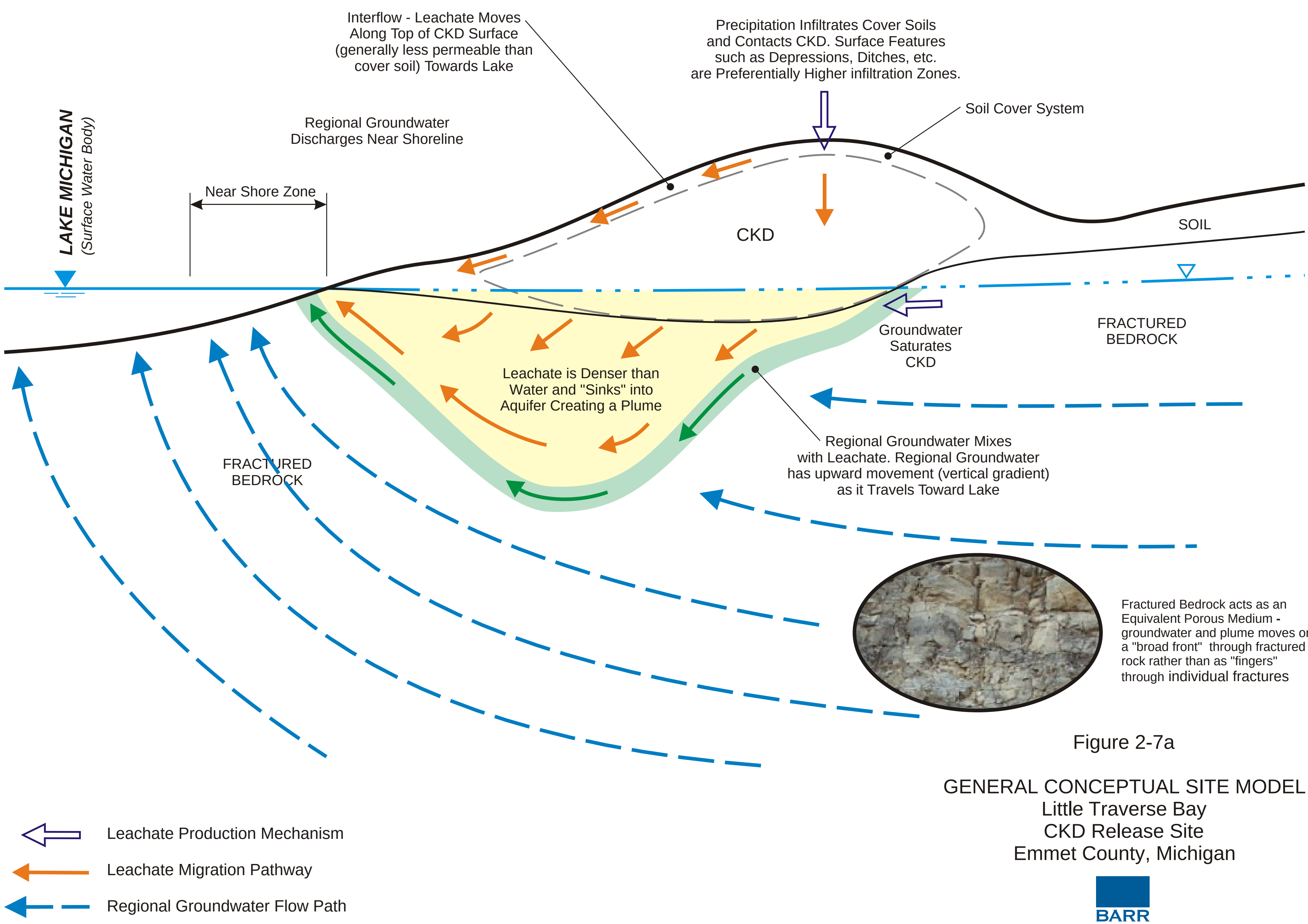


Figure 2-7a

GENERAL CONCEPTUAL SITE MODEL
Little Traverse Bay
CKD Release Site
Emmet County, Michigan

BARR

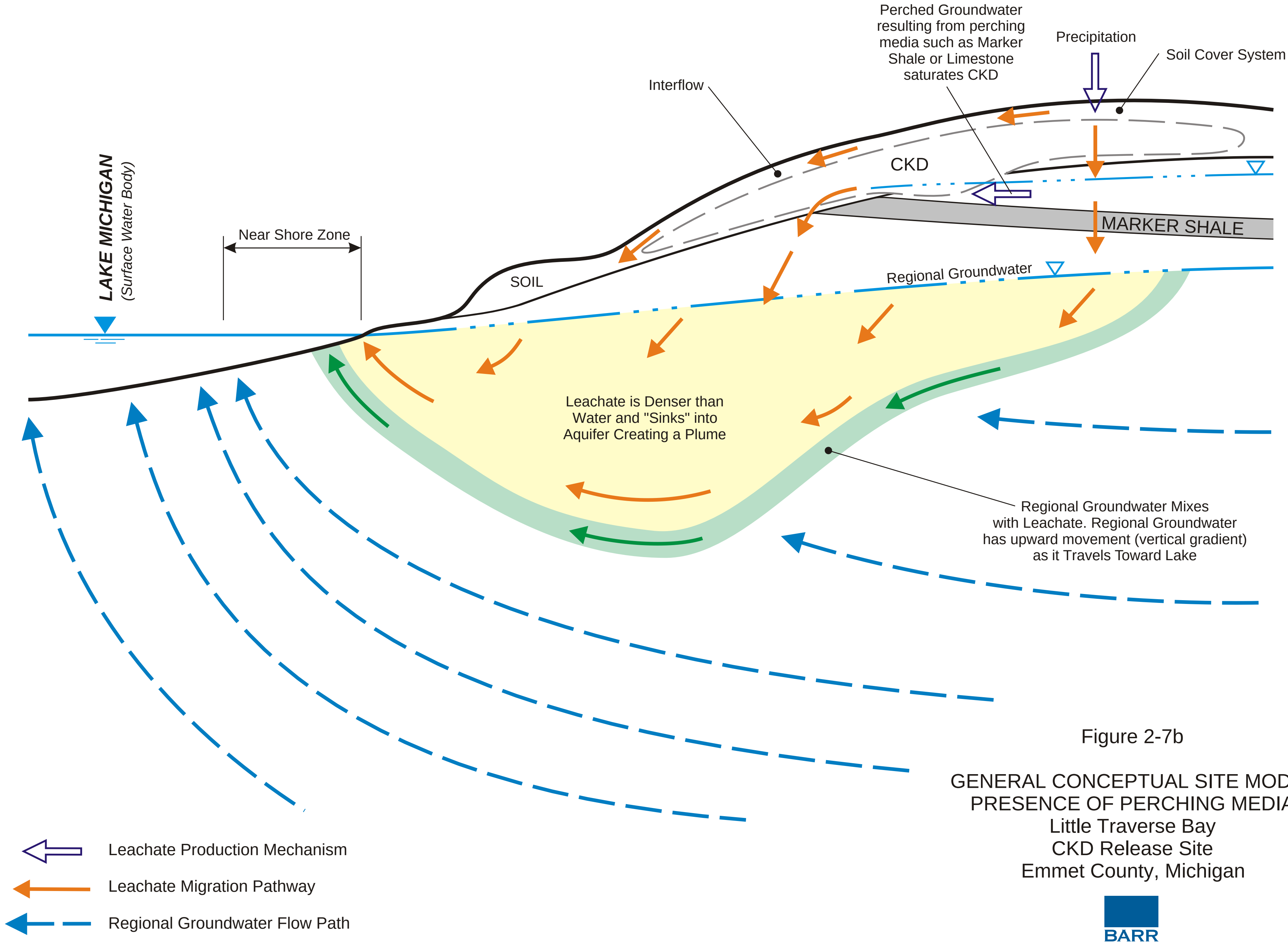


Figure 2-7b

GENERAL CONCEPTUAL SITE MODEL
PRESENCE OF PERCHING MEDIA
Little Traverse Bay
CKD Release Site
Emmet County, Michigan

BARR

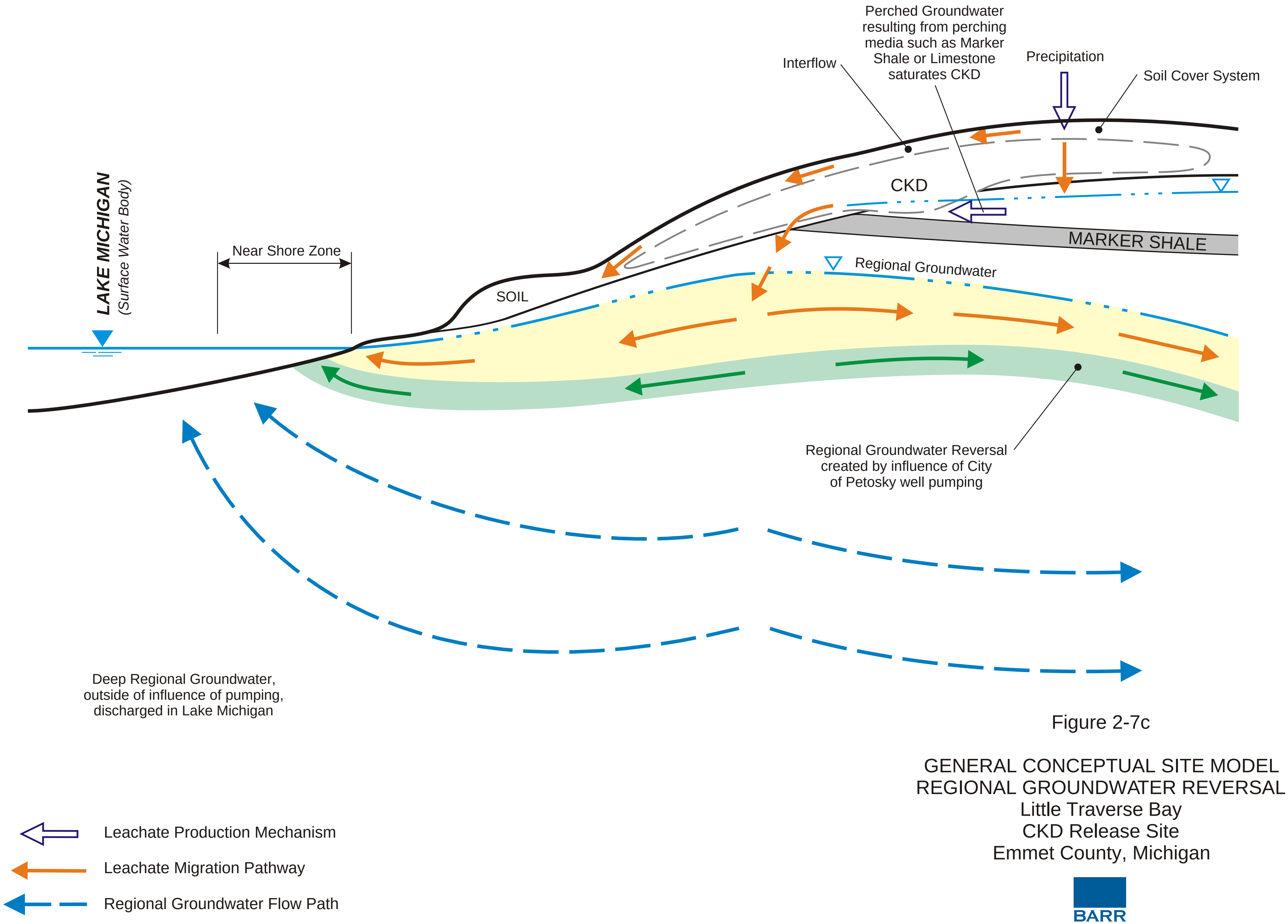
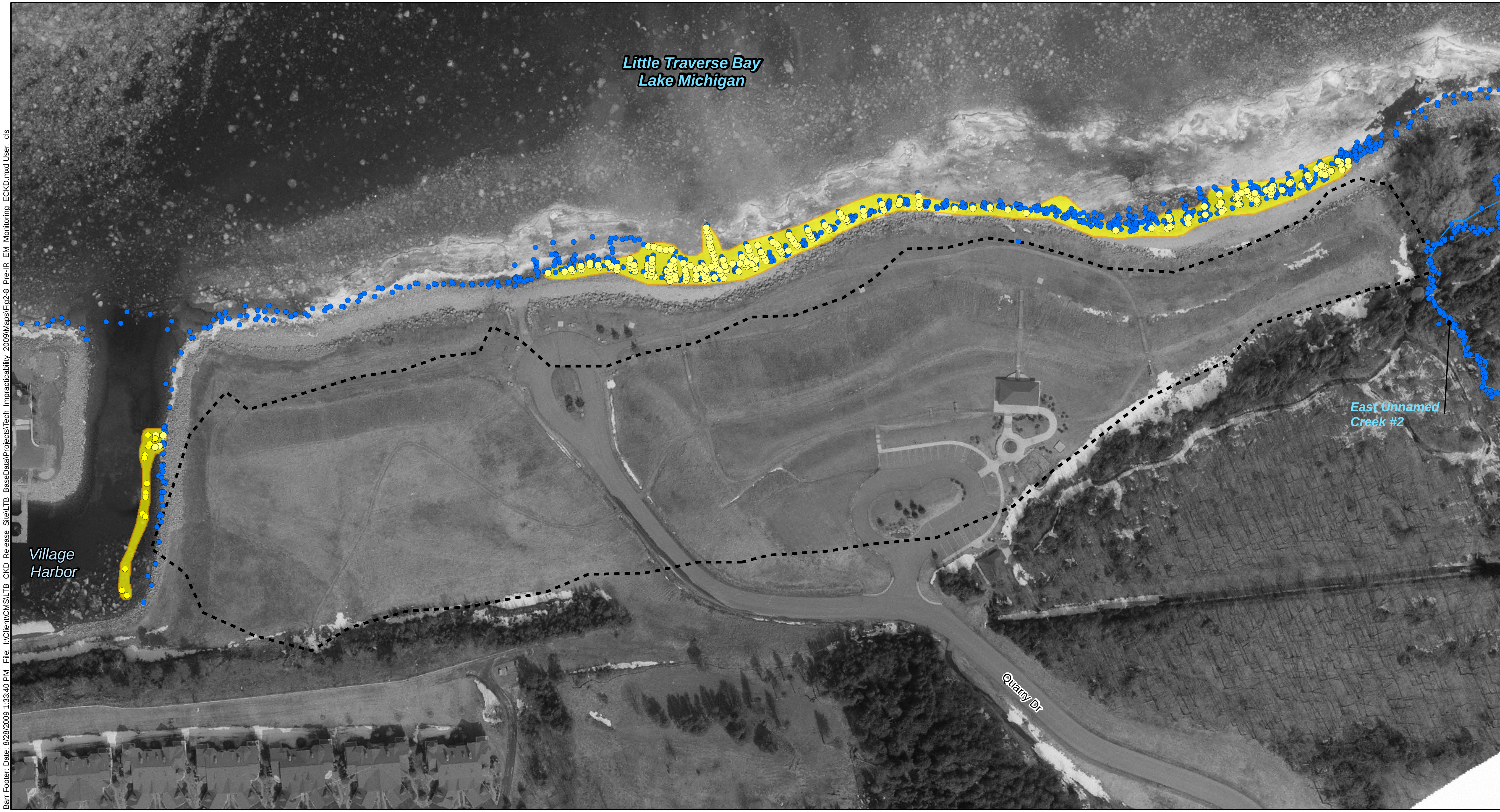


Figure 2-7c

GENERAL CONCEPTUAL SITE MODEL
REGIONAL GROUNDWATER REVERSAL
Little Traverse Bay
CKD Release Site
Emmet County, Michigan

BARR



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Imagery: April 2005

Barr Engineering pH Monitoring Points

- pH value equal to or greater than 9.0 in Surface Water
- pH value less than 9.0 in Surface Water

pH readings are from 2005 and 2006 (effectiveness monitoring, targeted lakeshore survey, and operational monitoring)

Approximate CKD Extent (Original)

Observed Leachate Discharge Zone

N

125 62.5 0 125

Feet

Figure 2-8

SURFACE WATER QUALITY (pH) PRE-IR
EAST CKD AREA
Little Traverse Bay
CKD Release Site
Emmet County, Michigan

BARR

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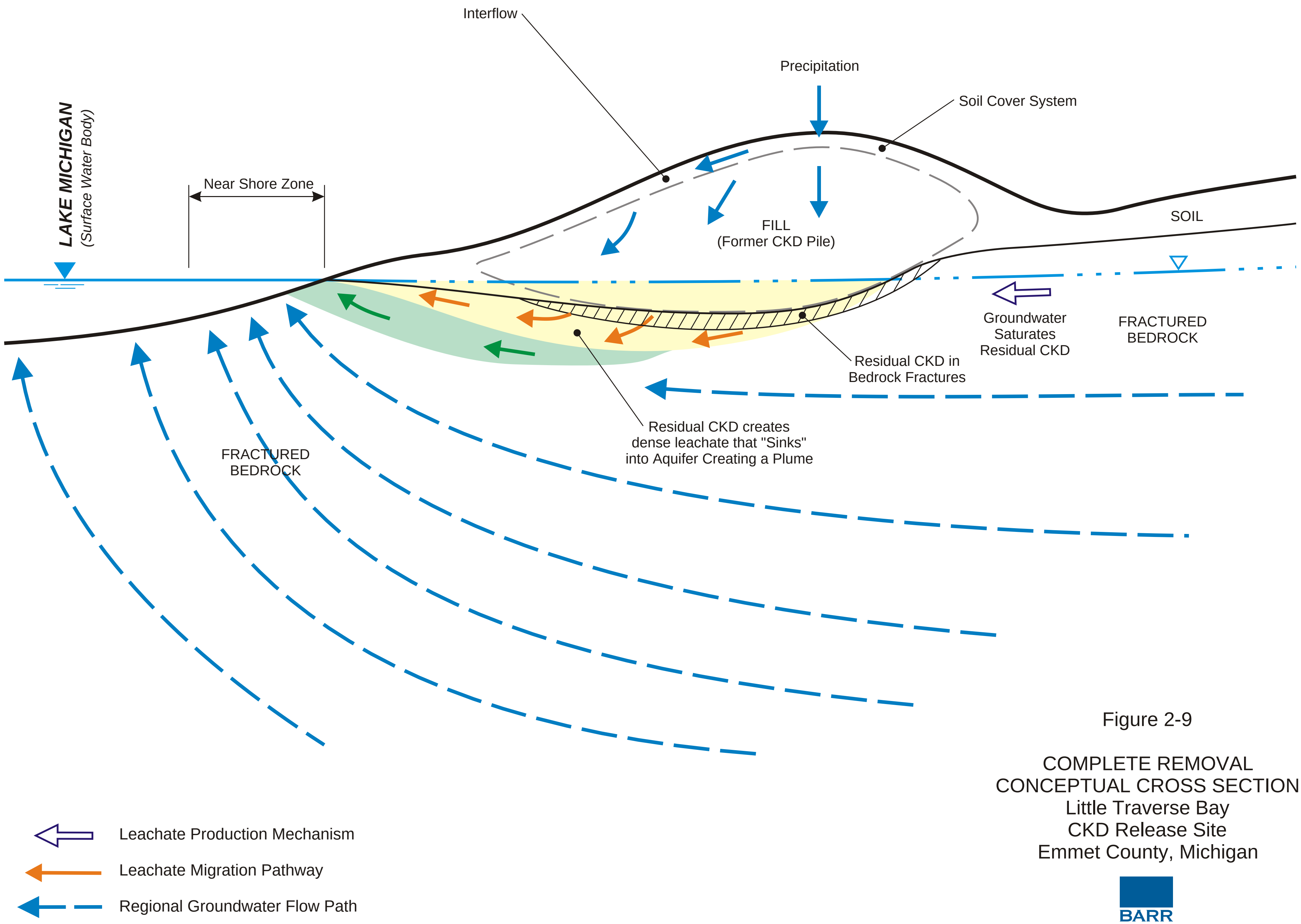

Figure 2-9

COMPLETE REMOVAL
CONCEPTUAL CROSS SECTION
Little Traverse Bay
CKD Release Site
Emmet County, Michigan

BARR

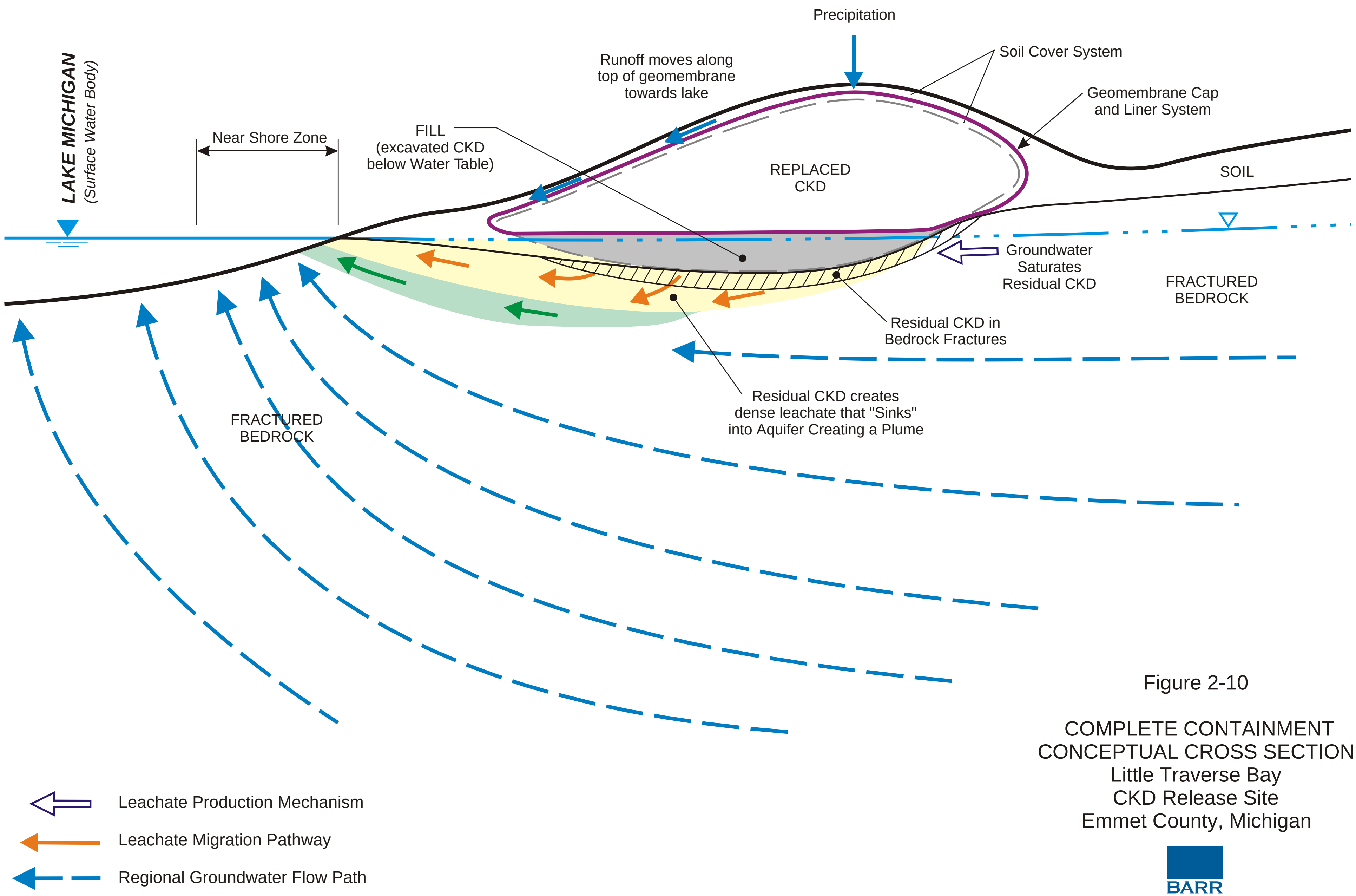

Figure 2-10

COMPLETE CONTAINMENT
CONCEPTUAL CROSS SECTION
Little Traverse Bay
CKD Release Site
Emmet County, Michigan

BARR

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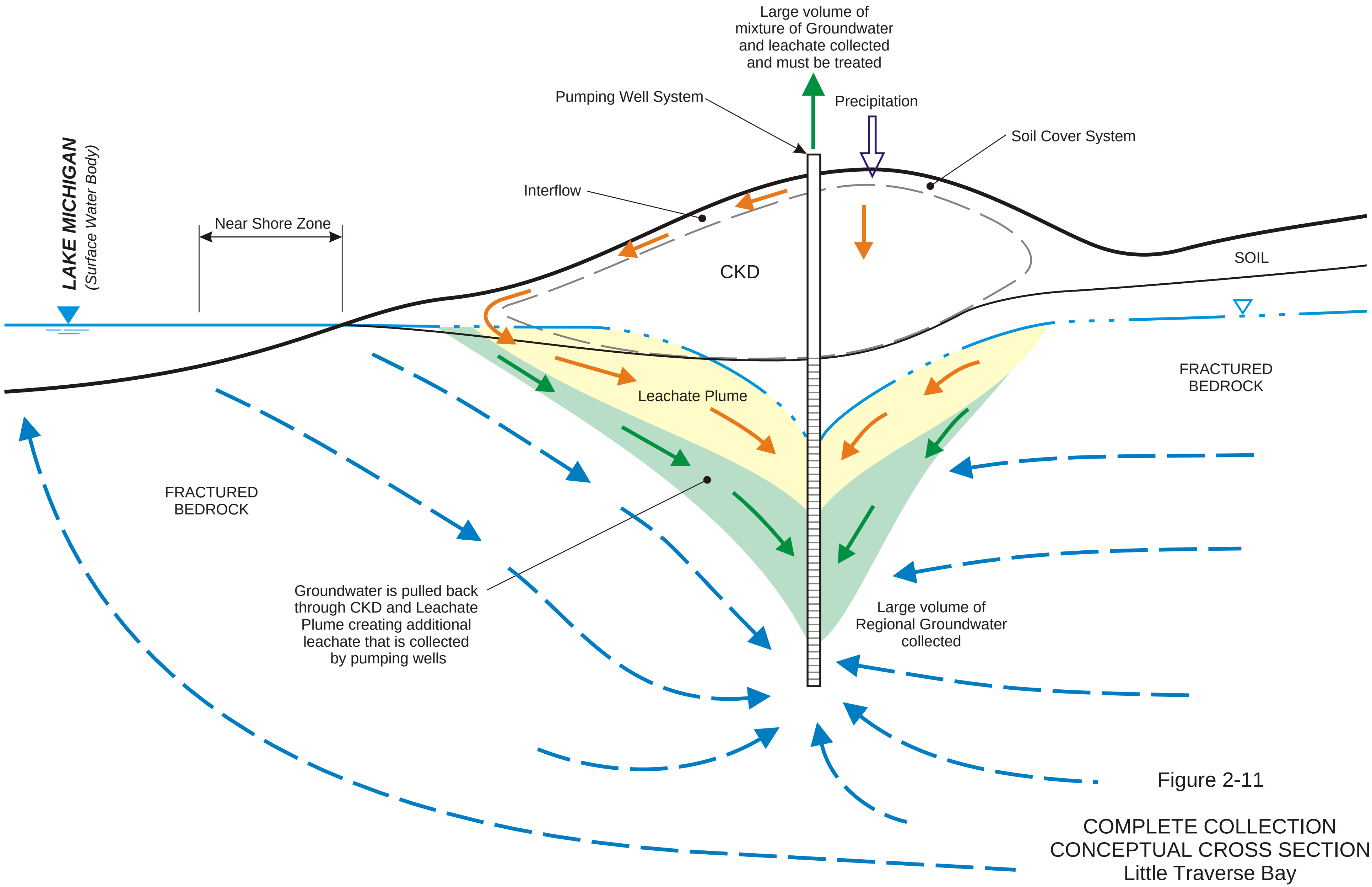

Leachate Production Mechanism

Leachate Migration Pathway

Regional Groundwater Flow Path

Figure 2-11

COMPLETE COLLECTION
CONCEPTUAL CROSS SECTION
Little Traverse Bay
CKD Release Site
Emmet County, Michigan

BARR

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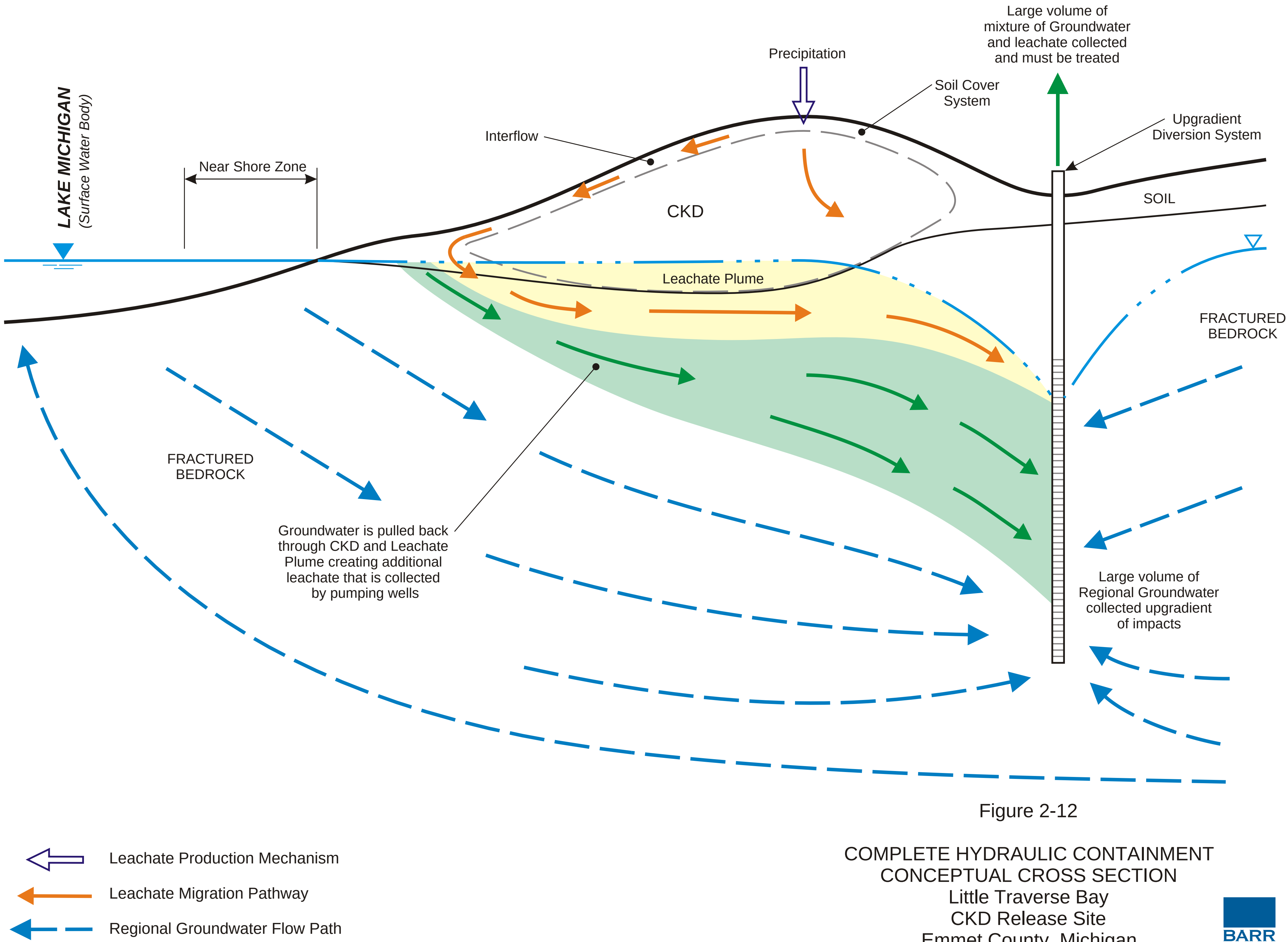
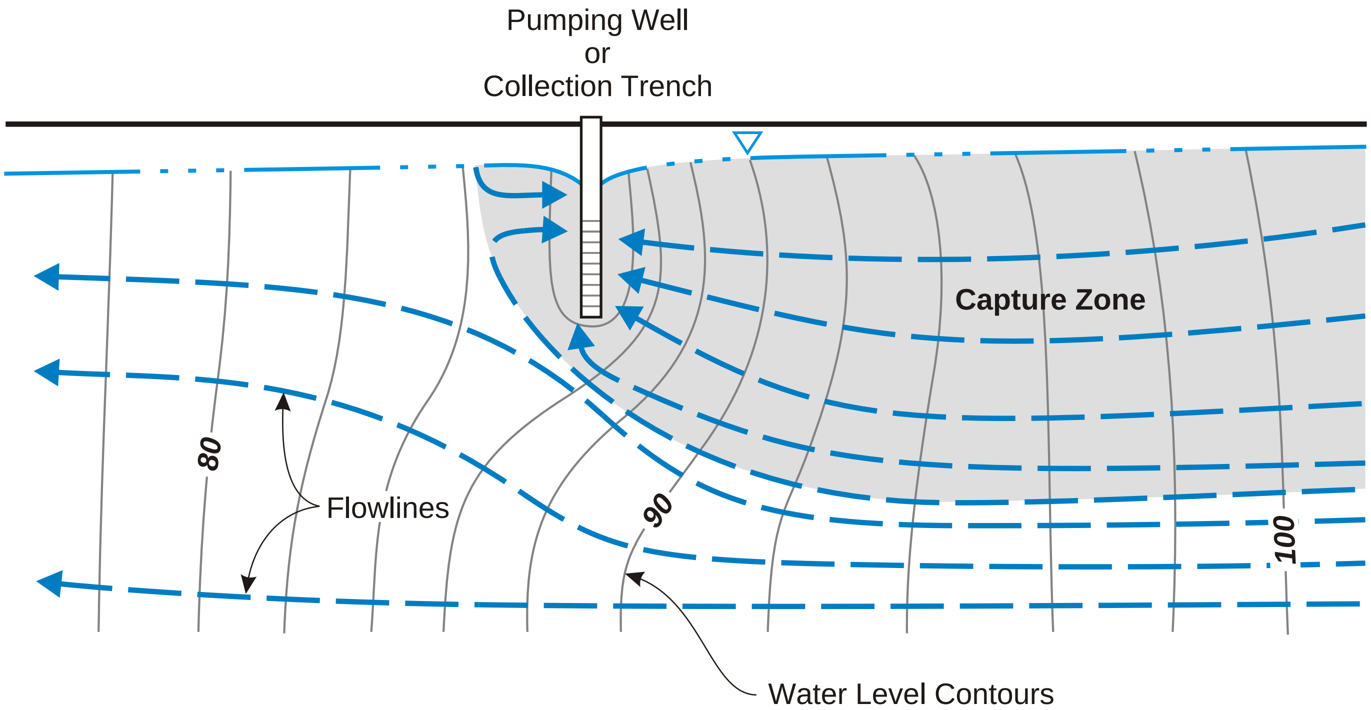


Figure 2-12

COMPLETE HYDRAULIC CONTAINMENT
CONCEPTUAL CROSS SECTION
Little Traverse Bay
CKD Release Site
Emmet County, Michigan

BARR

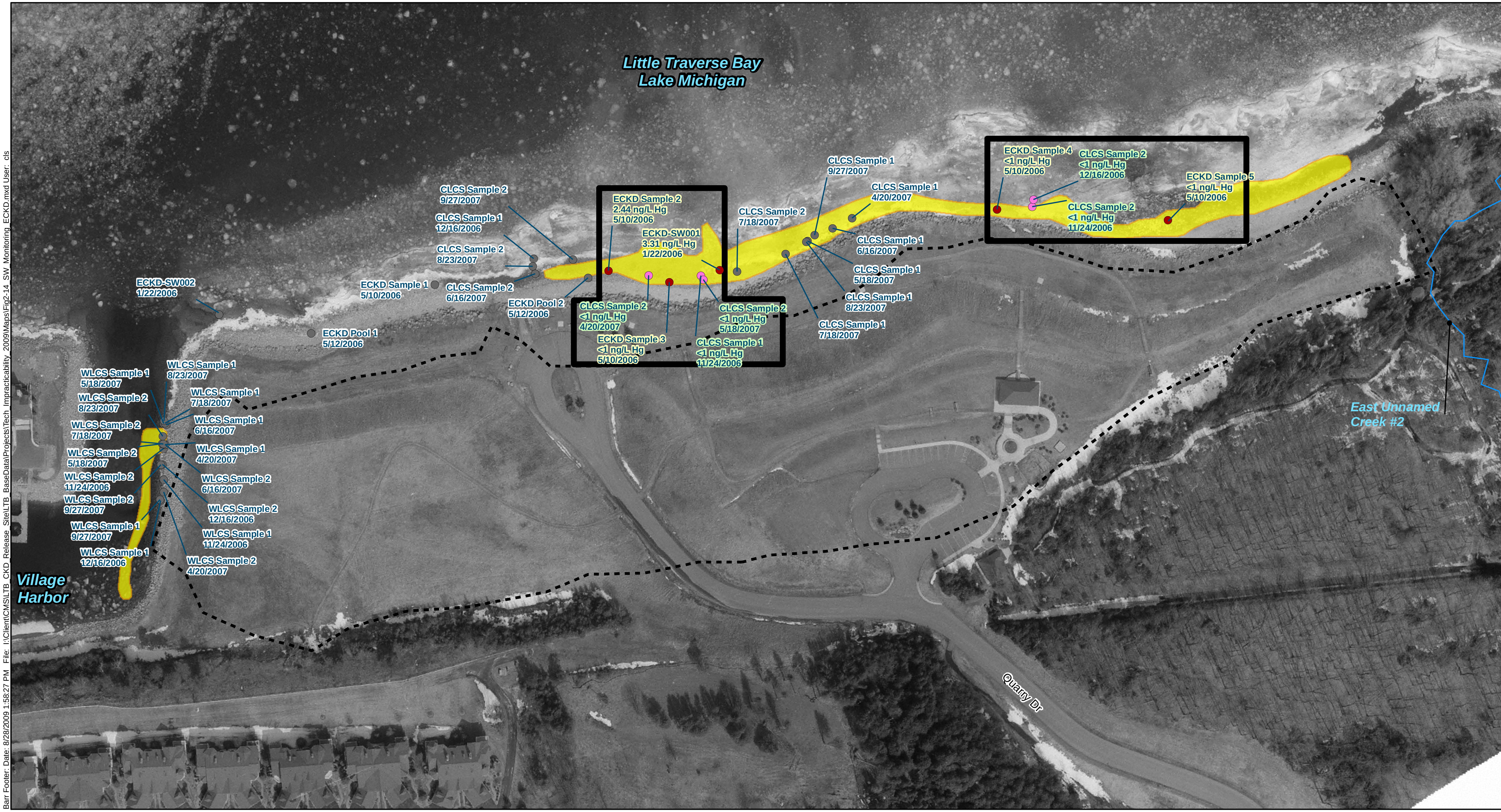


SOURCE:
Adapted from U.S. EPA, 2008. Figure 1, illustration of vertical capture zone, from "A Systematic Approach for Evaluation of Captures Zones at Pump and Treat Systems." EPA 600/R-08/003, January 2008.

Figure 2-13

CONCEPTUAL CAPTURE ZONE
Little Traverse Bay
CKD Release Site
Emmet County, Michigan

BARR



Imagery: April 2005

- Surface Water Monitoring Locations

Samples Discussed in Section 4

- Samples collected prior to interim response actions
- Samples collected following implementation of interim response actions

- Approximate CKD Extent (Original)
- Observed Leachate Discharge Zone
- Surface Water Evaluation Area

N

125 62.5 0 125 Feet

Figure 2-14

SURFACE WATER MONITORING
EAST CKD AREA
Little Traverse Bay
CKD Release Site
Emmet County, Michigan

BARR

Imagery: April 2005

pH Monitoring Points

- pH value equal to or greater than 9.0 in Surface Water
- pH value less than 9.0 in Surface Water

pH readings are from 2009 effectiveness monitoring

Approximate CKD Extent (Existing)

Former Observed Leachate Discharge Zone

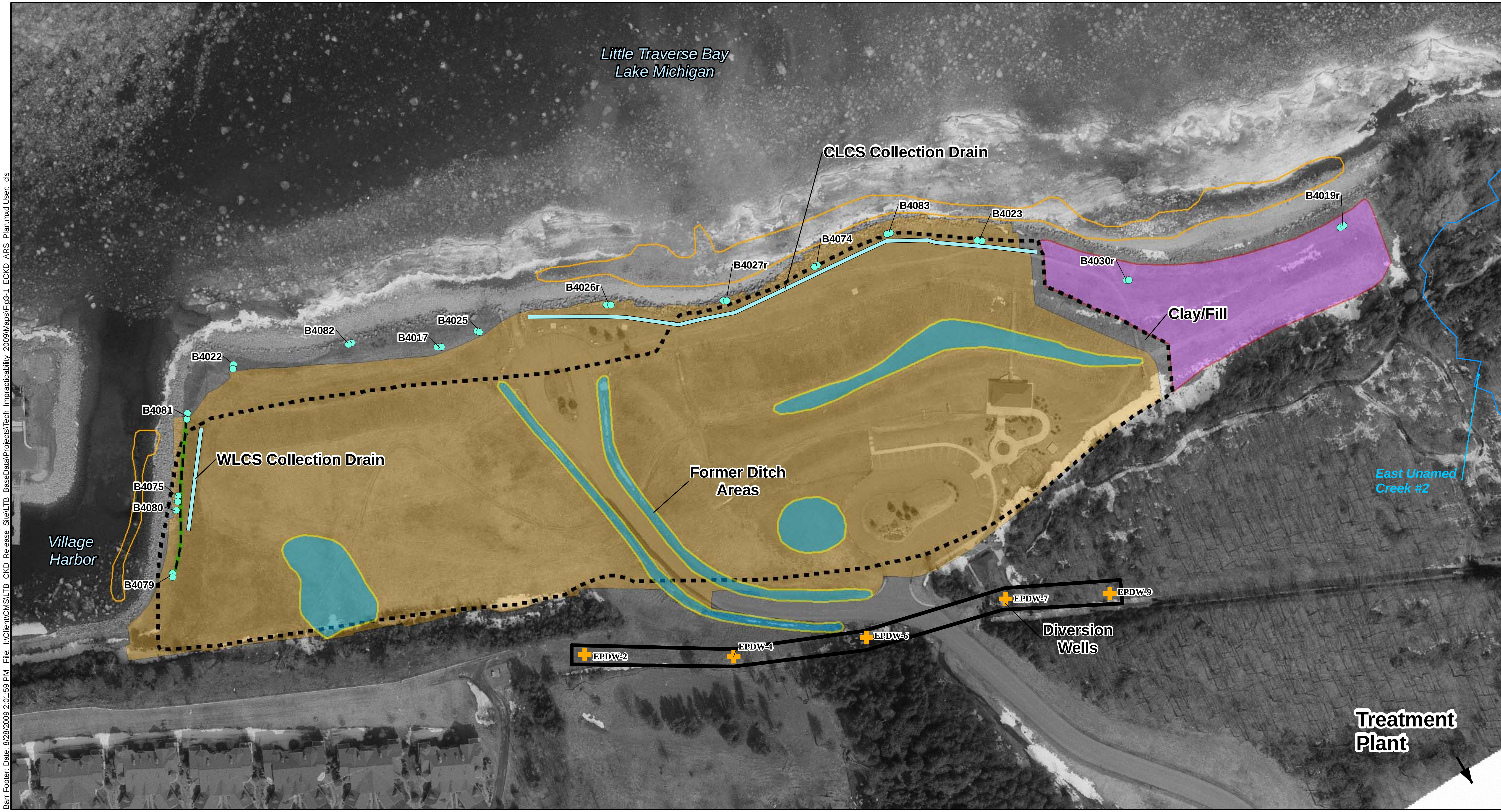
N

125 62.5 0 125 Feet

Figure 2-15

SURFACE WATER QUALITY (pH) POST-IR
EAST CKD AREA
Little Traverse Bay
CKD Release Site
Emmet County, Michigan

BARR



Imagery: April 2005

- GSI Monitoring/Flux Well Nest (Existing)
- Diversion Well
- Slurry Wall
- Collection Drain
- Approximate CKD Extent (Existing)
- CKD Removal Extent
- Cap Area
- Surface Water Drainage Improvement Areas
- Proposed Groundwater Diversion Corridor
- Former Observed Leachate Discharge Zone

N

125 62.5 0 125
Feet

Figure 3-1

ALTERNATIVE REMEDIAL STRATEGY PLAN
EAST CKD AREA
Little Traverse Bay
CKD Release Site
Emmet County, Michigan

BARR

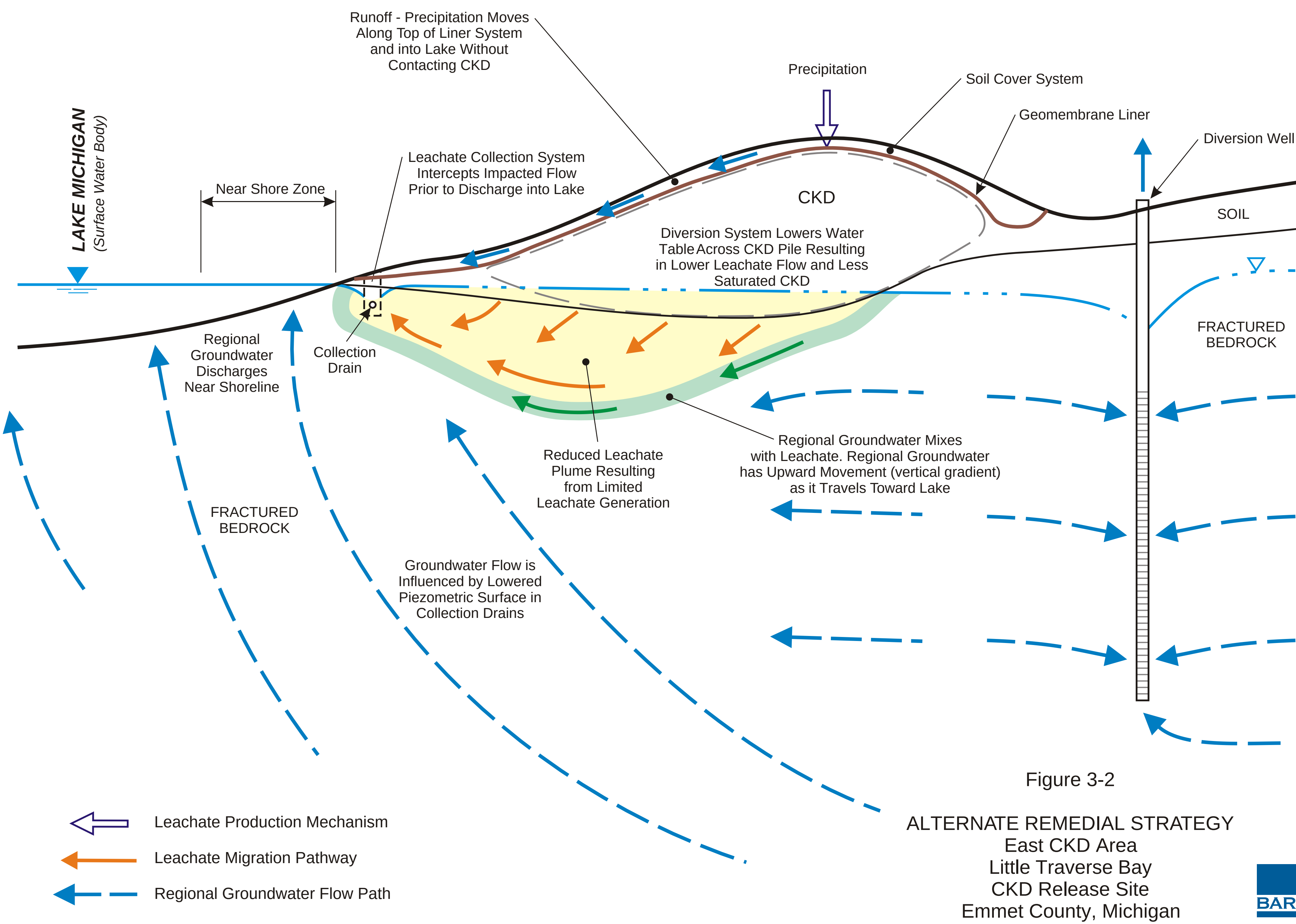


Figure 3-2

ALTERNATE REMEDIAL STRATEGY
East CKD Area
Little Traverse Bay
CKD Release Site
Emmet County, Michigan

BARR

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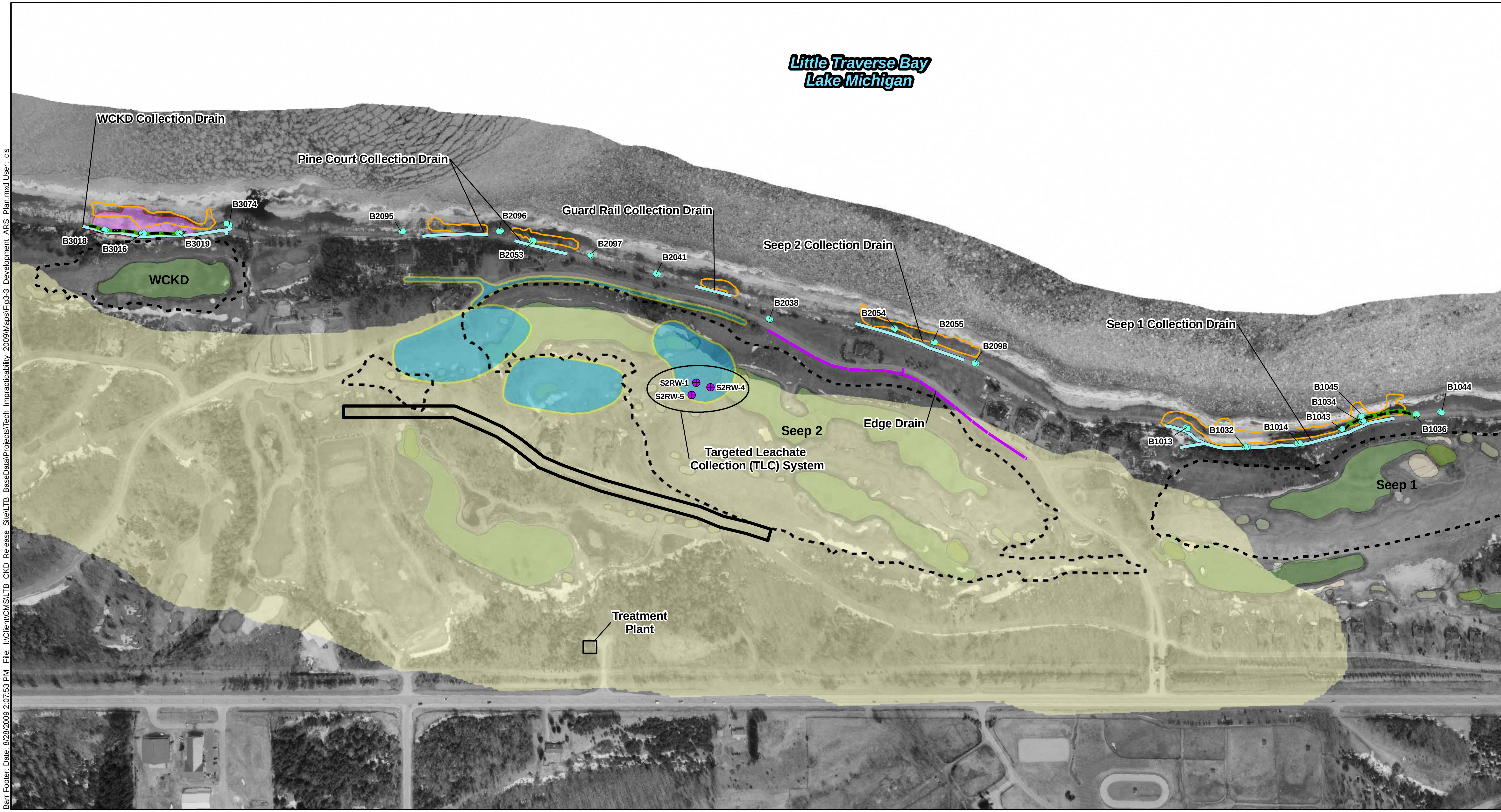

Imagery: April 2005

- Targeted Leachate Collection (TLC) Recovery Well
- Collection Drain
- Edge Drain
- Barrier Wall (Slurry or MFZ)
- Approximate CKD Extent (Existing)
- CKD Removal Extent
- Proposed Perched Groundwater Diversion Corridor
- Proposed Surface Water Drainage Improvement Areas
- Approximate Shale Extent
- Former Observed Leachate Discharge Zone

N

400 200 0 400 Feet

Figure 3-3

ALTERNATIVE REMEDIAL STRATEGY PLAN
DEVELOPMENT AREA
Little Traverse Bay
CKD Release Site
Emmet County, Michigan

BARR

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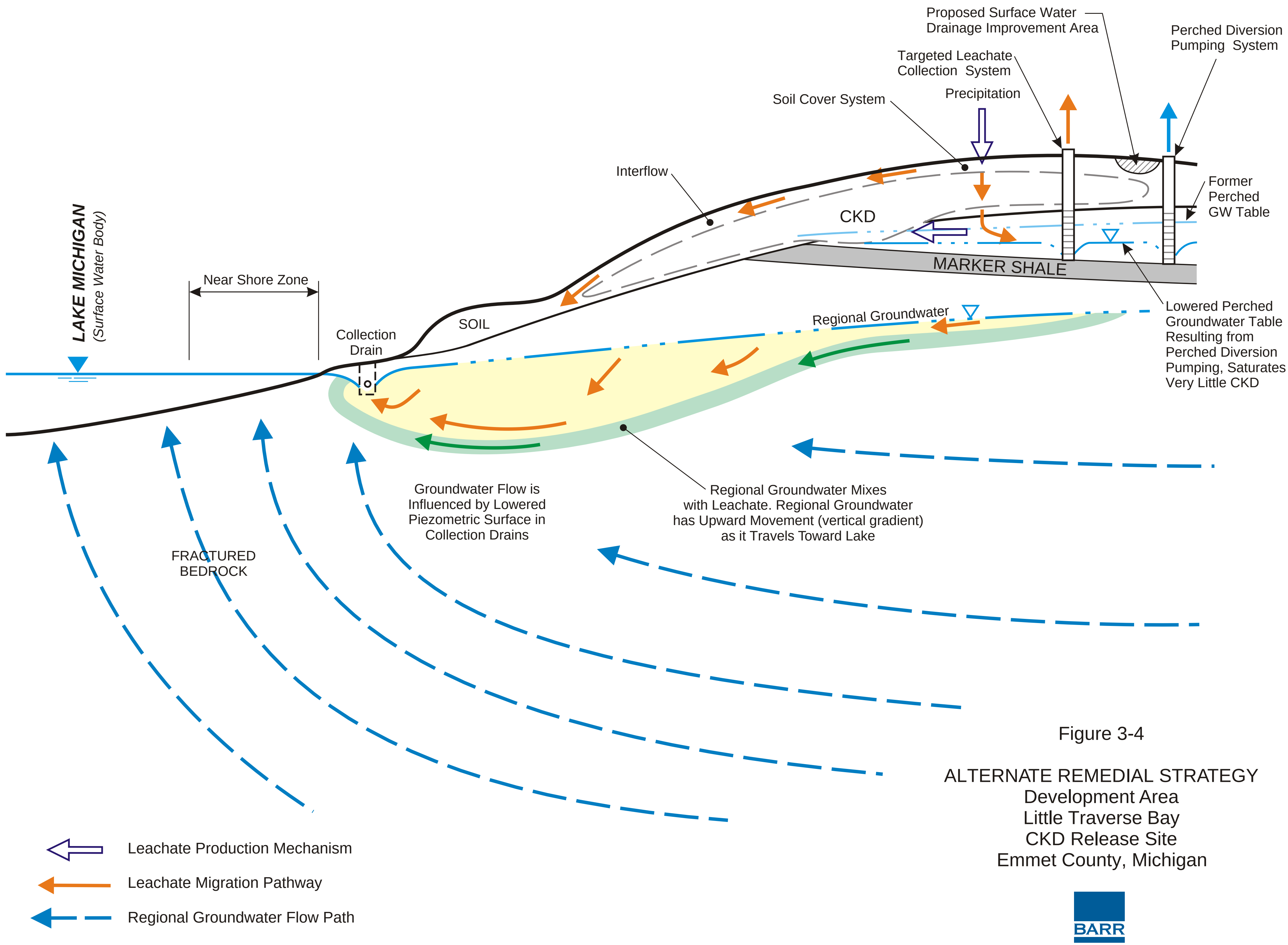

Figure 3-4

ALTERNATE REMEDIAL STRATEGY
Development Area
Little Traverse Bay
CKD Release Site
Emmet County, Michigan

BARR

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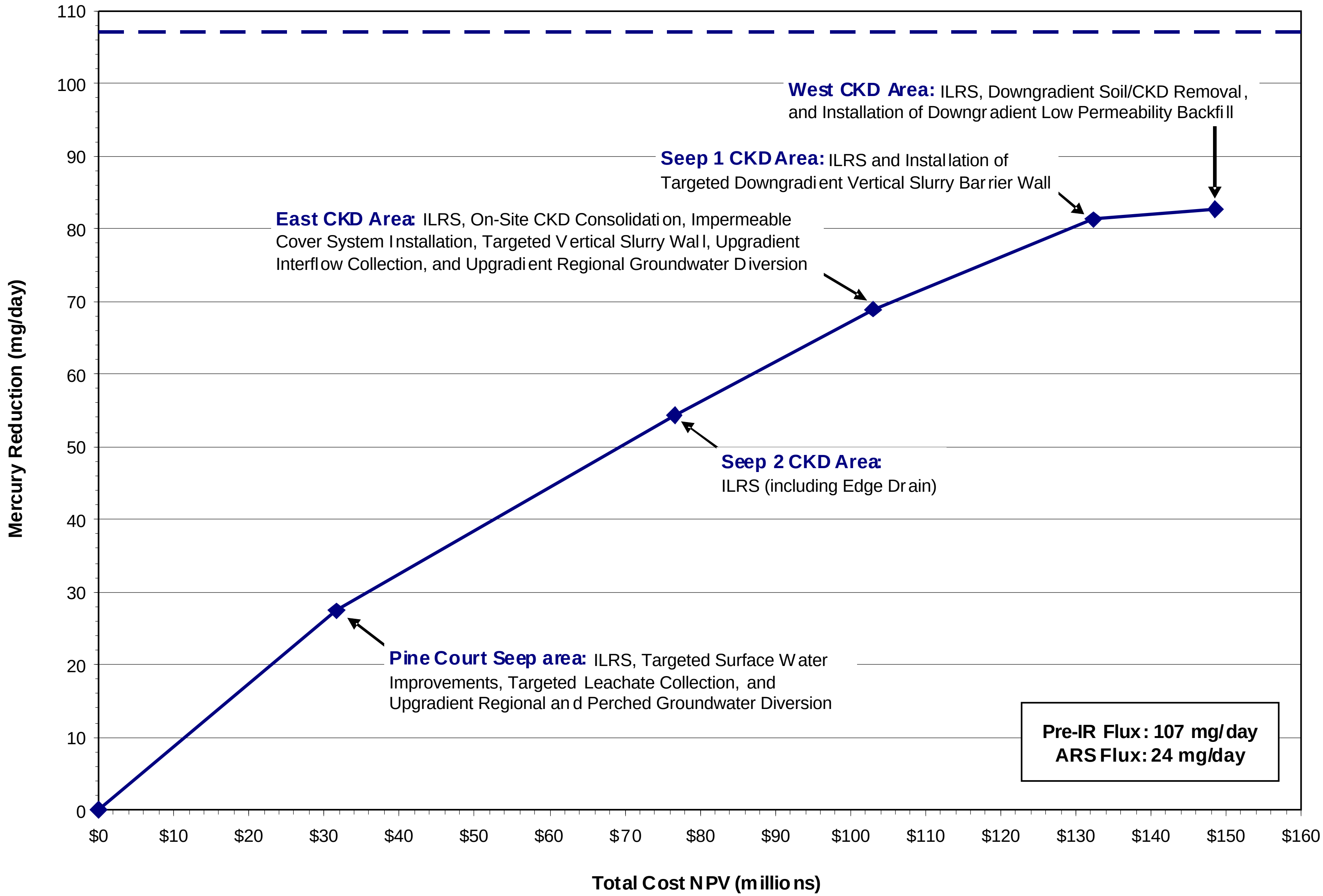


Figure 3-5

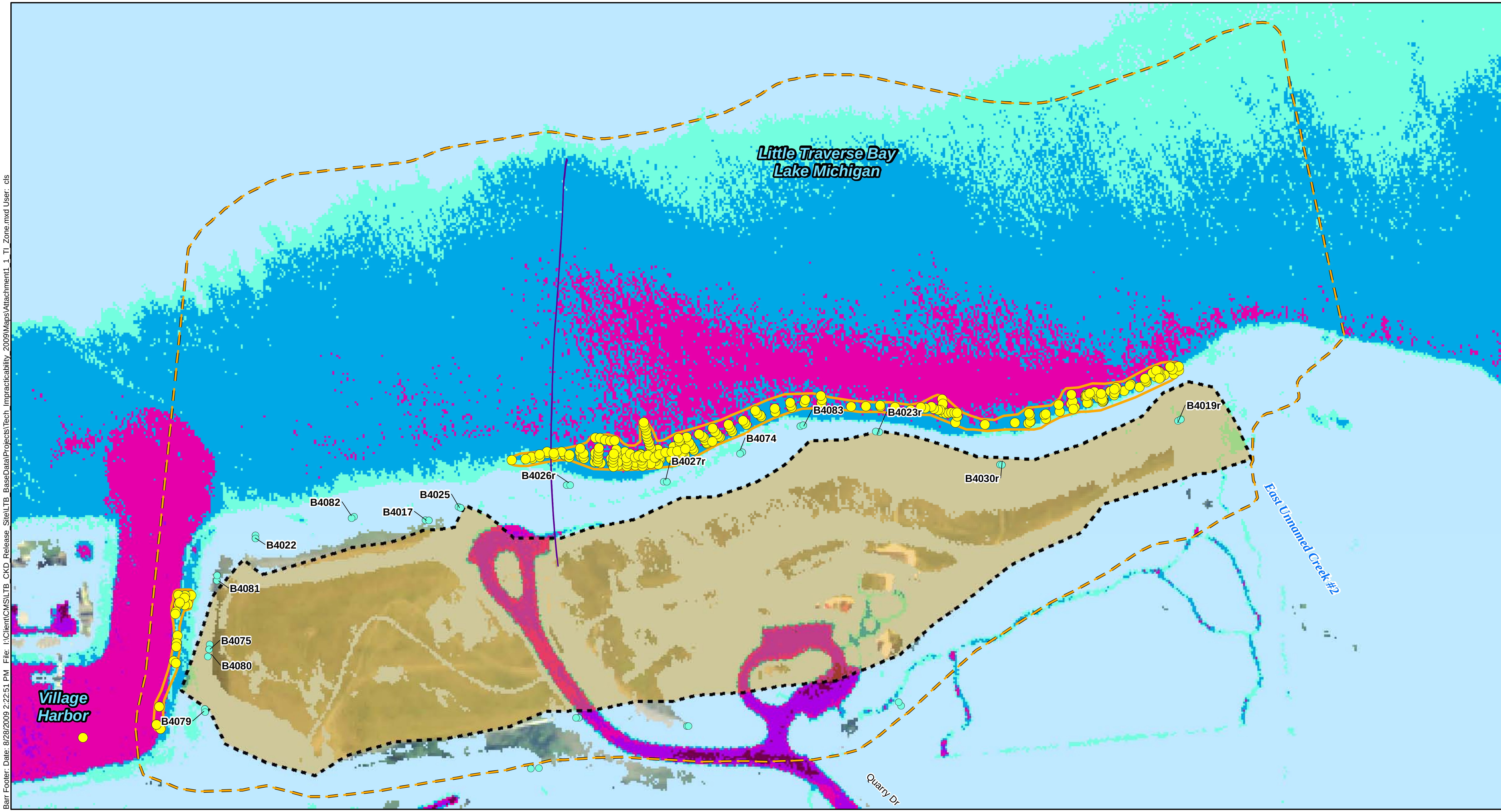
MERCURY REDUCTION AND TOTAL COST
ALTERNATIVE REMEDAIL STRATEGY
Little Traverse Bay
CKD Release Site
Emmet County, Michigan

BARR

Attachments

Attachment 1

Aerial Thermometry and Particle Tracking Images



Imagery: 2005 USDA-FSA-APFO NAIP

GSI Monitoring Well Nest (Existing)
Barr Engineering pH Monitoring Points
pH value equal to or greater than 9.0 in Surface Water
Former Observed Leachate Discharge Zone

Aerial Thermometry
- 0 - 4.00 ºC
- 4.01 - 5.00 ºC
- 5.01- 6.00 ºC
- 6.01 - 7.00 ºC
- 7.01 - 8.00 ºC
- 8.01 - 9.00 ºC
- 9.01 - 12.00 ºC

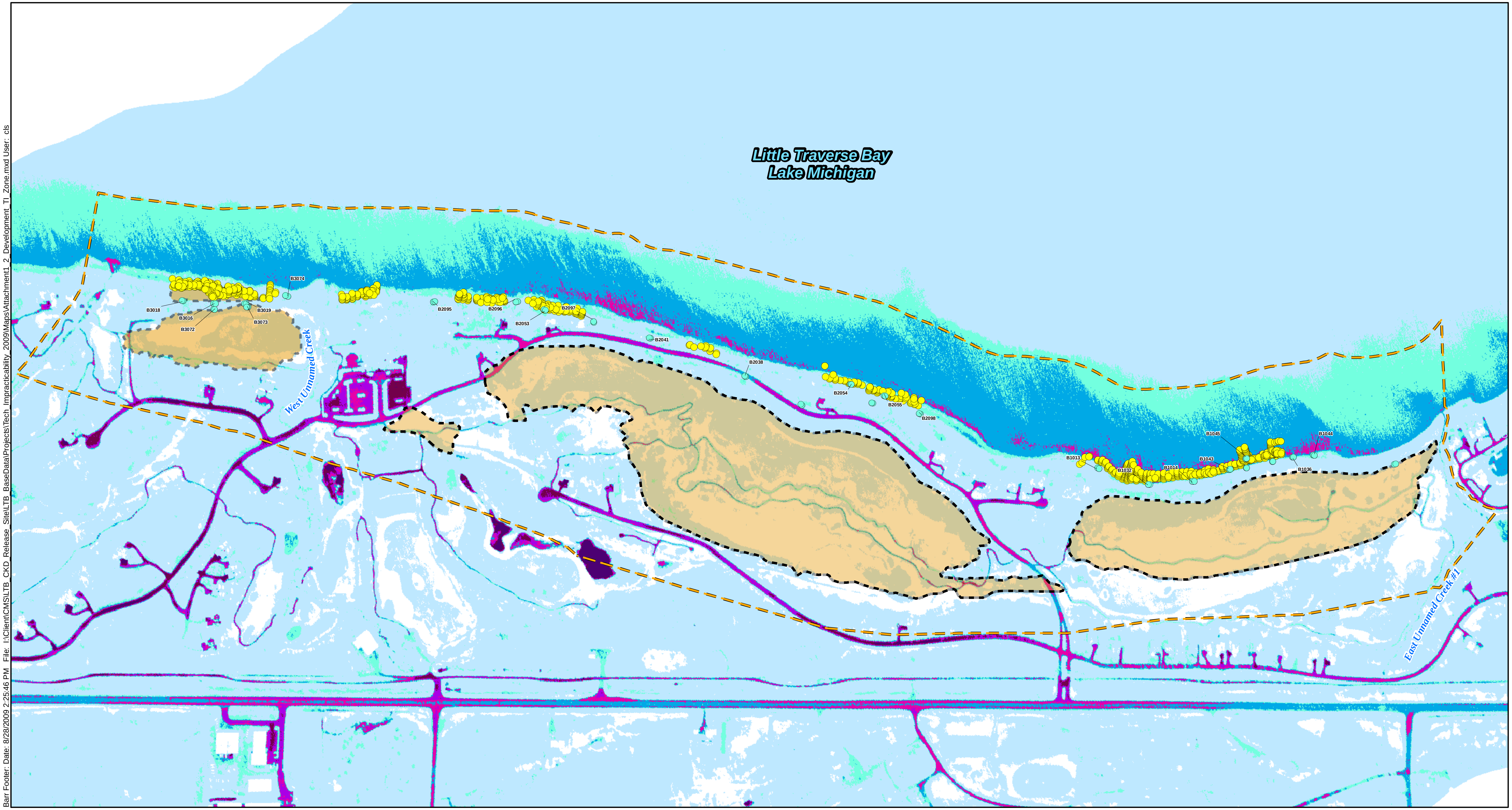
N

150 75 0 150
Feet

Attachment 1-1

TECHNICAL IMPRACTICABILITY ZONE
EAST CKD AREA
Little Traverse Bay
CKD Release Site
Emmet County, Michigan

BARR



Imagery: 2005 USDA-FSA-APFO NAIP

GSI Monitoring Well Nest (Existing)

Barr Engineering pH Monitoring Points

pH value equal to or greater than 9.0 in Surface Water

Aerial Thermometry

- 0 - 4.00 ºC
- 4.01 - 5.00 ºC
- 5.01- 6.00 ºC
- 6.01 - 7.00 ºC
- 7.01 - 8.00 ºC
- 8.01 - 9.00 ºC
- 9.01 - 12.00 ºC

N

500 250 0 500 Feet

Attachment 1-2

TECHNICAL IMPRACTICABILITY ZONE
DEVELOPMENT AREA
Little Traverse Bay
CKD Release Site
Emmet County, Michigan

BARR